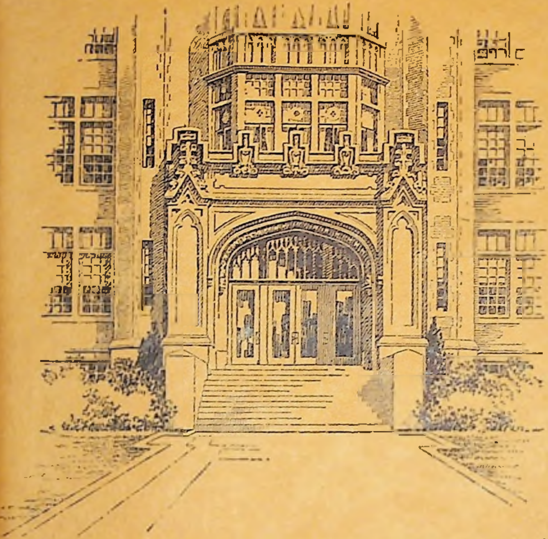

International Correspondence Schools
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Hydrographic Surveying

PREPARED ESPECIALLY FOR HOME STUDY

By
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HYDROGRAPHIC SURVEYING

Serial 787 Edition 2

SURVEY OF OUTLINE OF A BODY OF WATER

1. Definition and Object of Hydrographic Surveying.—Hydrographic surveying comprises all surveys of lakes, streams, reservoirs, or other bodies of water. Its object may be:

1. To obtain sufficient information from which to draw an outline map of the body of water surveyed.

2. To determine, in addition, the elevations of a sufficient number of points on the bottom below the water surface to define the subaqueous contours of the containing valley or basin.

3. To determine the form of a portion of the bottom of the sea, a bay, harbor, or navigable river, for purposes of navigation. In this case, it is necessary to locate the navigable channels, and the obstructions to navigation, such as shoals, rocks, sunken wrecks, etc.

2. Limitations.—Hydrographic surveying consists merely in making the measurements necessary for acquiring such information as is outlined above. The measurement of the velocity and discharge of rivers and streams, and the planning and execution of works of improvement, such as the reclamation of submerged areas or the construction of breakwaters, sea walls, dams, etc., belong to hydraulic engineering, and will not be treated here.

3. Traverse Survey.—The survey of a body of water to determine its outline may be conducted as an ordinary traverse by any of the methods described in *Transit Surveying*.

The courses of the traverse are run at convenient distances from the water's edge and the shore line is determined by measurement from the line of the survey. The position of the ordinary low-water line is usually defined, but in many cases the high-water line is also determined and noted.

A good way to make an outline survey of a body of water is by means of a deflection traverse, using a transit and a

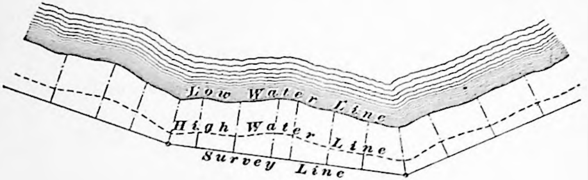

FIG. 1

chain or tape. This method is commonly used and is satisfactory for ordinary surveys of this kind. The outline survey of a body of water can also be made by the transit and stadia; this method of surveying is fully described in *Stadia and Plane-Table Surveying*. The entire survey of a small

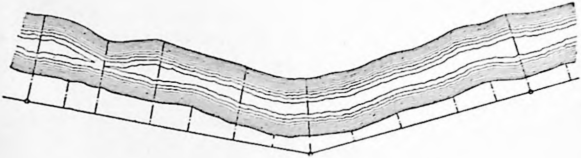

FIG. 2

river or stream, including the location of soundings, can be made with the stadia.

Prominent objects on shore may be located by direct measurement from the line of survey. If at a considerable distance, they may be located by triangulation, by taking sights from two known points. The distances from the line of the survey to the high- and low-water lines are usually measured by offsets, as illustrated in Fig. 1. If it is not necessary to obtain a close approximation of the shore outline,

the offset measurements can be omitted and the shore line between the survey stations sketched in by the eye.

In the case of a small stream, a traverse run along one bank is usually sufficient. The offsets should be measured to the edge of the water, and the width of the stream also measured at sufficiently close intervals to give the required information, as shown in Fig. 2. In the case of a small lake, the traverse is run entirely around it and closed on the point of beginning.

4. Triangulation.—A triangulation survey probably affords the best means for determining the outlines of large rivers, lakes, and other large bodies of water. Triangulation, as applied to hydrographic surveying, consists: (1) in locating distant objects from a measured base; (2) in determining the surface outlines of a river or other body of water by a system of triangles referred to a measured base.

The base line should be measured on fairly level ground in a location convenient for making the angular measurements from its ends. It should be not less than 500 feet long and as much longer as practicable. The ends should be marked with substantial stakes or with stone monuments. The line should be measured carefully with a steel tape.

5. Locating Distant Objects.—For locating points of reference and other distant objects, the angle formed by the intersection of the base line and the line of sight to the object, at each end of the base line, is measured. From the values of these angles and the length and azimuth of the base line, the lengths and azimuths of the lines to the object can be calculated and the object located. Let AB, Fig. 3, represent a base line and C a distant object whose position is to be determined. The base line AB is measured accurately, and the angles ABC and BAC are measured with a transit or

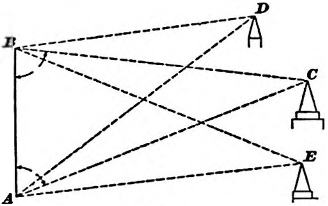

FIG. 3

sextant. Then, in the triangle $A\,B\,C$, the side $A\,B$ and the adjacent angles $A\,B\,C$ and $B\,A\,C$ are known, from which the sides $A\,C$ and $B\,C$ can be calculated by trigonometry, and the point C located. The points D and E can be located in a similar manner from the same base line.

6. Triangulation of River.—For the survey of a river or other body of water by triangulation, points are selected on both sides for the vertexes of the triangles. Such points are called **triangulation stations.** They should be so located as to give triangles of advantageous form, in which no angle will be less than 30° or greater than 120°. Fig. 4 illustrates the triangulation of a river for the purpose of determining the outline of its shores. Some convenient line, as the line *1–3*, is taken as the base, its length is carefully measured, and its azimuth is either determined or assumed. The angles from *1* and *3* to *2*, and the angle *2*, are carefully measured. Their sum should not differ from 180° by more than 1 minute. The difference between that sum and 180° is distributed equally among the three angles of the triangle, one-third of it being added to, or subtracted from, each angle, as may be necessary to bring the sum to 180°. The same applies to the other triangles, in each of which each angle should be measured directly.

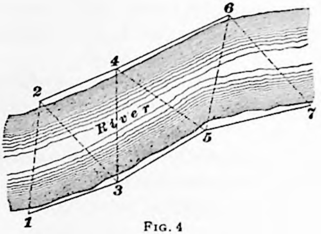

Fig. 4

Knowing the angles of the triangle *1–2–3*, and the length of *1–3*, the lengths of *1–2* and *3–2* are computed by trigonometry. Then, in the triangle *2–3–4*, the angles and the side *2–3* are known, and the other two sides are computed; and so on with the other triangles. At the end of the chain of triangles another line, as *5–7*, whose length has been calculated, is measured, as a check on the work.

The shore line between triangulation stations can be sketched in approximately, or, if it is desired to determine its outline more closely, the more important points can be located with transit and stadia, or by intersections from two triangulation stations when these are so situated as to give satisfactory intersections. If more detailed information is desired, a traverse can be run between adjacent stations and the shore line located by offsets at such intervals as may be desired.

SURVEY OF A SUBMERGED AREA

7. Purpose of Survey.—A hydrographic survey to determine the topography of the bottom of the basin or channel containing a body of water may be made for one or more of the following purposes:

1. To determine what changes it is desirable or necessary to make in the configuration of the channel or basin under consideration.
2. To indicate where material should be removed by dredging or blasting and where it may be deposited for filling, and to measure the quantity of material removed or the extent of the filling.
3. To obtain the information necessary for planning the construction of sea walls, jetties, lighthouses, docks, bridge piers, etc.
4. To construct a map or chart of the channel or basin for navigation purposes.
5. To determine the volume of the body of water, or capacity of the containing basin.

In making the survey of a submerged area, it is first necessary to make an outline survey in order to determine the shore line and locate points of reference. The points of reference are usually on shore and may be located by direct measurement or triangulation, as may be more expedient. In some cases, buoys are anchored in the water and used for reference points; as they are inaccessible, their distances from other points of reference must be determined by computation.

FIG. 5

SOUNDING

8. Soundings.—The shore line having been determined and the reference points located, the next step is to measure the depths, below the water surface, of a sufficient number of points to show the configuration of the bottom; such measurements are called **soundings.** For depths of 18 feet or less, soundings are made with a graduated wooden rod called a **sounding pole.** For greater depths, a line having a weight attached is necessary; this is called a **lead line.**

9. Sounding Pole.—The sounding pole may be of any sound, straight-grained wood. It should be well seasoned to prevent warping, and the bottom end should be provided with a disk-shaped iron shoe, not less than 5 inches in diameter, to prevent the rod from sinking into the soft mud of the bottom.

A good form of sounding pole is illustrated in Fig. 5. Poles of this kind are usually made of white pine finished smooth and round. The length is usually from 15 to 20 feet, and the diameter from 3 to $3\frac{1}{2}$ inches at the lower end and from 2 to $2\frac{1}{2}$ inches at the upper end. The lower end of the pole is formed by an iron shoe that terminates in a disk, as shown.

The pole is painted white and is graduated to feet and tenths, the zero of the graduation being at the bottom of the shoe. Each foot division is marked by a red band about $\frac{3}{8}$ inch wide, and each tenth division by a black band about $\frac{3}{16}$ inch wide; the bands extend entirely around the pole. The graduations are numbered by two sets of figures placed on the pole diametrically opposite each other. The

numbers designating feet are painted in red and those designating tenths in black.

The bottom of the shoe is sometimes hollowed out cup-shaped for the purpose of bringing up samples of the bottom over which the soundings are taken. When samples of the bottom are desired, the cavity is lined with grease or tallow, to which particles of the sand or mud of the bottom will adhere.

10. Lead.—The weight attached to a sounding line is called the **lead**, because it is usually made of that material. It should be long and slender, and should taper slightly toward the upper end, so as to reduce its resistance to being raised in the water. The form shown in Fig. 6 is frequently used. An iron rod R has molded around it the lead L, which is usually square in cross-section, as shown at S, and of sufficient size to give the requisite weight. Small cross-bars attached to the rod prevent the lead from slipping. At the lower end of the rod is attached the cup C, which is covered with a leather washer W that slides freely on the rod between the cup and the lead. When the lead is lowered to the bottom, the cup sinks far enough into the bottom to fill, and the leather cover prevents the contents from being washed out while the lead is being drawn to the surface. In some cases the cup is omitted and the bottom of the lead hollowed out in conical form. When it is not desired to know the composition of the bottom, a plain lead of nearly cylindrical form, but tapering toward the upper end, will answer the purpose. For still, shallow water, a lead weighing about 5 pounds is satisfactory. A lead weighing 10 pounds is suitable for depths under 40 feet in reasonably quiet water. For greater depths and in strong currents the weight of the lead should be from 15 to 20 pounds.

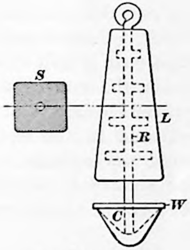

FIG. 6

11. Sounding Line.—Preferably, the sounding line should be of strong, closely plaited linen or twisted hemp.

Sometimes a cotton rope or a wire chain is used, but the use of such materials is not recommended. The line should be of a size suited to the weight of the lead; for ordinary river or lake soundings, about $\frac{3}{8}$ inch in diameter is a good size. It is marked with leather or cloth tags, which are inserted between the strands of the line. For river and harbor surveys, the tags are placed at intervals of 1 foot. At every fifth or tenth interval a conspicuous tag, usually of a bright color, is used. The zero of the graduation is the bottom of the lead.

Before being measured and marked, the line should be thoroughly stretched. This is done by stretching it tightly between two posts or trees, or wrapping it closely around a post or smooth-barked tree, then fastening both ends, wetting thoroughly and allowing it to dry. The slack is then taken up and the operation repeated until the line shows no further slack. Care should be taken not to stretch it too much, as in that case it will shorten in use. The length of the lead line, from the end of the lead to each 10-foot mark, should be tested before and after each day's use, and the results entered in the notebook. The line should preferably be kept under water when not in use; if it is not, it should be soaked in water for $\frac{1}{2}$ hour and then tested for length before the sounding is commenced.

12. Sounding Party and Equipment.—When the soundings are located by means of observations made with instruments stationed on the shore, the sounding party may consist of the recorder, leadsman, and boat crew. If the soundings are located by the stadia method, a stadia rodman is added to the sounding party. When the soundings are located from the boat, the sounding party is usually composed of two observers, a recorder, a leadsman, and the boat crew.

The usual equipment of a sounding party consists of a sounding pole or lead line and two signal flags, one white and one red. The flags are used to signal to the instrumentman on shore when a sounding is being taken, if the soundings are located by an instrument on shore. The white flag

is shown for each sounding except every fifth one, when the red flag is shown. The recorder is provided with a notebook in which to enter depths of soundings, nature of bottom, etc.

13. Making the Soundings.—If the depth of the water does not exceed about 75 feet, the soundings can usually be made while the boat is in motion. When the soundings are made at long intervals and the depth of the water does not exceed about 30 feet, it is usually more advantageous to withdraw the lead from the water after each sounding. In this case the lead is cast far enough ahead of the boat, as each sounding is made, for the line to become vertical when the lead reaches the bottom. If the depth of the water is too great for this method, the soundings can be made at intervals, as the boat moves, without drawing up the lead farther between soundings than is necessary to free it from the bottom.

As the soundings are made, the leadsman calls out the observed depth of each sounding to the recorder, who repeats the depth to prevent mistakes and then enters it in his notebook, together with the time and the number of the sounding. The character of the bottom is observed and noted at such intervals as may be desired, and all changes in the material of the bottom are noted.

GAUGES

14. Tide Gauges.—The bottom depths, as determined by the soundings, are measured from the surface of the water, the elevation of which varies considerably in river and tidal waters. In order to reduce the observed depths to the same surface of reference or to the datum of the survey, it is necessary to know the water level at the time each sounding is made. For this purpose a gauge that will show the height of the water surface should be established at some convenient place. An ordinary graduated board or staff is best for temporary use. This may consist of a board about 6 inches wide, 1 inch thick, and of a length somewhat greater than the variation in the height of the water, painted white and

graduated to feet and tenths in black. Such gauges are used very commonly for this purpose, and are called **staff gauges.** A simple form of staff gauge is shown in Fig. 7. For facilitating the reading of the gauge, a float, consisting of a small board painted white, may be so placed as to rest on the water surface in front of the gauge. This float moves up or down with the water surface as it rises or falls, and indicates at once the gauge reading.

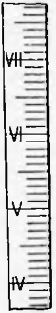

FIG. 7

15. Location of Gauges.—A tide gauge may be attached to a dock, quay wall, pile, stake, tree, or any other stationary object that is in a convenient position and to which the gauge can be secured in a vertical position. Sometimes the gauge is divided into sections and fastened to different objects, as trees, according to their heights, as illustrated in Fig. 8. Each section should slightly overlap the other, so as to afford a continuous gauge reading. In some cases, the gauge may be conveniently set at any suitable inclination and attached to stakes driven firmly in the bank. It may be made in sections and fastened to stakes in such a manner as to conform to the slope of the bank, as illustrated in Fig. 9. Each section should consist of a straight, well-seasoned board from 4 to 6 inches wide and 1 inch thick, and should be painted white. The divisions are determined with the level and should be marked by nails or tacks driven into the face of the board. Such a gauge should be located where the bank is not changing by caving off or filling up, and should be in

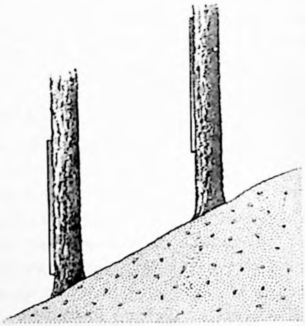
FIG. 8

a location where it will not be disturbed by floating drift at periods of high water. A gauge so placed can be easily observed from the bank at any height of the water.

When a continuous record of the fluctuations of the water surface in tidal waters is desired, a self-registering gauge should be used. This consists essentially of a float that rises and falls with the tide. The float is protected by a perforated box and is so arranged that its motion is recorded by a stylus or pencil on a roll of paper, which passes over a cylinder that is revolved at a uniform speed by clockwork. The path of the pencil on the paper indicates the stage of the water at any given time.

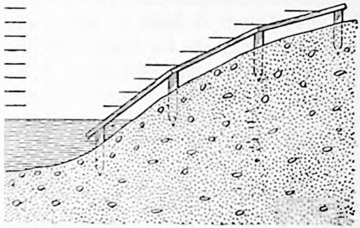

FIG. 9

THE SEXTANT

16. Law of Reflection.—Let AB, Fig. 10, be a plane mirror; PO, a ray of light meeting the mirror at O; OP', the direction taken by the ray after it strikes the mirror; and ON, a line perpendicular to the plane of the mirror. This perpendicular is called the **normal** to the mirror at O. The ray PO coming to the mirror is called the **incident ray**, and the angle NOP that it makes with the normal is called the **angle of incidence.** The ray OP' leaving the mirror is called the **reflected ray**, and the angle NOP' that it makes with the normal is called the **angle of reflection.** It is a general law of physics that the angle of incidence is always equal to the angle of reflection; that is, $NOP = NOP'$. It follows that the angles POA and $P'OB$ are also equal.

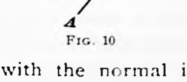

FIG. 10

17. Description of Sextant.—The sextant is a hand instrument for measuring angles. By means of it the angle between two lines of sight can be measured by a single operation. The angle between two lines of sight directed to two objects is commonly spoken of as the **angular distance** between the objects. When making the observations, the instrument is held in the hand, and successive angular measurements can be made with great rapidity. It is therefore especially adapted for use in a boat on the water, where the motion renders the use of fixed instruments impracticable.

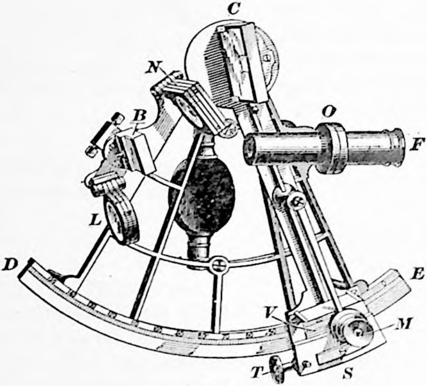

Fig. 11

As the sextant is frequently used in the location of soundings, a description of the instrument and a discussion of its theory are given here.

A sextant, as represented in Fig. 11, consists of a metal frame CDE, and an arm CS, called the **index arm**, which is fitted with a vernier and rotates about the center C of the sextant; to this index arm is also attached the **index mirror** BC, Fig. 12. To the arm CD is fixed the **horizon glass** A, half of the back of which is silvered, while the other half is transparent. The arm CE carries a **telescope** T directed

toward the horizon glass A. Thus, while the telescope is directed to an object H, the rays of light from another body S are reflected first from the mirror $B\,C$ to the silvered half of the mirror A, and then from this mirror to the telescope in the direction $H\,A\,T$. The observer will thus see both of the bodies H and S in the field of the telescope together.

In order that the ray of light $S\,C$ may enter the telescope after reflection, the index arm $B\,I$ must be turned about the pivot C until the mirror $B\,C$ is brought into the proper position with reference to $S\,C$ and A. When I is at E, the two mirrors are parallel; and when I has been moved forwards until the rays of light $S\,C$, after two reflections, enter the telescope, the arc $E\,I$ over which the arm $B\,I$ carrying the mirror $B\,C$ has been moved will be exactly equal to one-half the angle between • $S\,C$ and $H\,T$. Thus, the angle between the rays of light coming from two distant objects H and S may be measured as follows: The observer points the telescope directly toward H and then moves the arm I along the arc $E\,D$ until the reflected ray $S\,C\,A\,T$ also passes along the line $H\,A\,T$ and the image of the second object enters the telescope. The arc $E\,I$, which is equal to the angle, called the **index angle**, between the surfaces of the index mirror $C\,B$ and the horizon glass A, will then be one-half the angle between $S\,C$ and $H\,A$, that is, one-half the apparent angular distance of the bodies H and S.

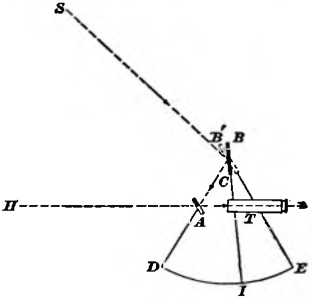

Fig. 12

Since the angle $E\,C\,I$ is one-half the true angle between $S\,C$ and $H\,A$, the arc $E\,D$ has each half degree marked as a whole degree, so that $E\,D$, which is an arc of 60°, is divided into 120 equal parts and each part marked 1°. This is done merely to spare the observer the trouble of multiplying the reading by 2.

18. Theory of the Sextant.—That the index angle, or angle between the index mirror BC and the horizon glass A is equal to one-half the angle between SC and HA, Fig. 13, will now be proved. With the index arm in any position,

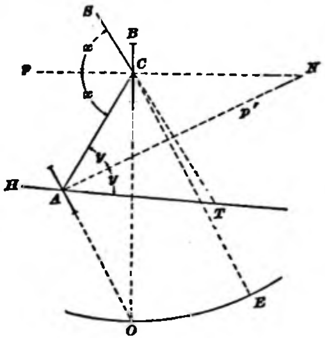

Fig. 13

produce the planes of the mirrors to their intersection at O, and produce the perpendiculars to the mirrors, pC and $p'A$, to their intersection at N. Since CE is the zero position of the index arm and CO its given position, the angle ECO is the index angle. Since CE is parallel to AO, $ECO = COA$, and since pC and $p'A$ are perpendicular to CO and AO, respectively, $COA = pNA$. Hence, $pNA = N$ is equal to the index angle.

It will be remembered that the ray of light SC, before reflection, makes the same angle with the perpendicular Cp as the ray of light CA after reflection. Hence, $SCp = pCA$, and similarly $CAp' = p'AT$. Calling each of the former angles x, for brevity, and each of the latter angles y, we have from the triangle ACN,

$$N = x - y$$

The observed angle is $STH = T$. From the triangle ACT,

$$T = 2x - 2y = 2(x - y) = 2N$$

whence, $$N = \tfrac{1}{2}T$$

That is, the angle between the two mirrors, or the index angle, is equal to one-half the angular distance between the two objects.

The vernier plate V, Fig. 11, is attached to the index bar immediately below the graduations on the limb. The index bar can be clamped to the limb by means of a clamp screw (not shown in the figure), and when so clamped can be

moved very slowly by means of the tangent screw *T*. The magnifying glass *M* is for reading the graduations on the limb and vernier. The two sets of colored-glass shades *N* and *L* are used when the sun is observed, in order to prevent the glare of its light from affecting the observer's eye; they are attached to the frame by hinges in such manner that the shades *N* can be turned into the path of the reflected ray and the shades *L* into the path of the direct ray.

19. The Vernier.—As stated previously, the divisions on the limb of a sextant correspond to degrees, and each division is subdivided into three, four, or six parts, according to the instrument. These divisions are numbered as shown in Fig. 14, the upper portion of which represents part of the limb of a sextant. The divisions representing degrees on the limb there shown are subdivided into three parts, each part representing a third of a degree, or 20 minutes. By means of the vernier shown in the lower part of the figure, however, the angles can be read to half minutes, or 30 seconds. The vernier of a sextant is substantially the same as that of a transit, except that it is single instead of double; that is, it reads in only one direction, to the left, from the zero point, instead of both to the left and to the right. The first line at the extreme right of the sextant vernier, which is usually designated by a spear-shaped mark, is the zero point or index mark of the vernier. The vernier shown in Fig. 14 is divided into forty equal parts, which together are equal to thirty-nine divisions on the limb. Since the least reading is equal to a scale division divided by the number of parts in the vernier, it is $\frac{20}{40}$ minute, or 30 seconds. The numbering of the vernier corresponds to whole

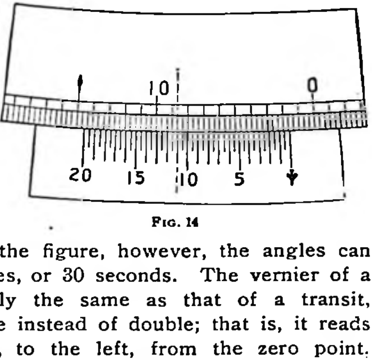

FIG. 14

minutes, which are represented by the longer graduations: the shorter graduations represent half minutes. Some sextants are graduated to read to 20 seconds and some to 10 seconds.

The graduations of the limb of a sextant usually extend a few degrees to the right of the zero mark, and it is sometimes convenient to make an observation that requires the vernier to be read when the index mark stands to the right of the zero mark. Such readings are said to be *off the arc.* When readings are made off the arc, the graduations are counted and the vernier is read to the right instead of to the left. The number of degrees and minutes are counted to the right from the zero mark to the first graduation at the left of the index mark; to this is added the number of minutes indicated by the coincident line of the vernier, as counted to the right from the graduation at the extreme left of the vernier. Thus, in Fig. 15, the index mark of the vernier stands to the right of the zero mark of the limb and the reading is off the arc. The angle is read by counting to the right on both the limb and vernier, as just described.

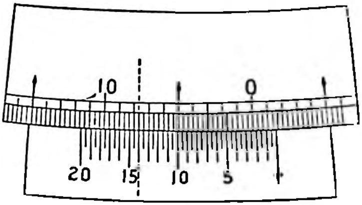

FIG. 15

20. Adjustments of the Sextant.

—There are four adjustments of the sextant, as follows:

1. To make the plane of the index glass perpendicular to the plane of the limb.

2. To make the plane of the horizon glass perpendicular to the plane of the limb.

3. To make the line of collimation of the telescope parallel to the plane of the limb.

4. To make the planes of the mirrors parallel when the index reading is zero.

21. To Adjust the Index Glass.—Place the index bar near the middle of the limb; with the eye near the plane of the limb, observe whether the limb as seen directly and its image as reflected in the index glass form a smooth continuous curve; if they do, the glass is perpendicular to the plane of the limb and the adjustment is correct. But if the reflected limb appears to be above that part of the limb seen directly, the glass leans forward; if the reflected limb appears to be below, the glass leans backward. In either case, the glass is made perpendicular to the plane of the limb by means of the adjusting screws at its base.

22. To Adjust the Horizon Glass.—Look through the telescope and horizon glass toward a star or other well-defined distant object. Move the index bar slowly until the reflected image passes over the image seen directly. If these images coincide, the horizon glass is perpendicular to the plane of the limb. If they do not coincide, the horizon glass is adjusted by an adjusting screw placed under, behind, or beside the glass, according to the construction of the instrument.

23. To Adjust the Telescope.—Place the sextant in a horizontal position on a table or other support, and direct the telescope at some well-defined point or mark about 20 feet away. Place two small blocks of equal height on the limb, one near each extremity. These blocks should be of exactly equal height, so that a line of sight over their tops will be parallel to the plane of the limb, and should be at the same height above the limb as the center of the telescope. Some sextants are provided with two small brass sights that can be placed on the limb for this purpose. Sight over the tops of the two blocks or through the sights, as the case may be, in the direction of the point or mark sighted through the telescope, and note if the line of sight intersects the mark. If it does not, but falls above or below the mark, the telescope is not parallel to the limb. It can be made parallel to the limb by means of the screws in the collar that holds the telescope. This adjustment, however, is not usually made

unless the error is considerable, since a slight lack of parallelism between the line of sight and the plane of the limb does not appreciably affect the angular measurements on the limb.

24. To Adjust Index or Find Index Error.—Set the index at zero, look through the telescope toward a star and note whether the direct and reflected images of the star coincide. If they do, the adjustment is correct. If they do not, move the index bar until they do coincide, and clamp it in this position. The reading of the index when in this position is called the **index error.** This error can be corrected by means of screws at the back of the index glass, which cause it to revolve about an axis perpendicular to the plane of the limb. To make the correction, set the index bar at zero and, by turning the screws, revolve the index glass until the two images exactly coincide. This adjustment will usually disturb the previous adjustment of the index glass, and, as a rule, it is not made unless the index error is greater than 3 minutes.

When the index error is less than 3 minutes, it is usually applied as a correction to all observations. If the error is *off* the arc, that is, if the index is to the right of the zero mark, it is additive or plus and should be added to all readings. If the error is *on* the arc, that is, if the index is to the left of the zero mark, the error is subtractive or minus and should be subtracted from all readings.

25. Method of Using the Sextant.—To measure an angle between two objects with a sextant, hold the plane of the limb in the plane of the two objects, look through the telescope toward the less distinct object, and move the index bar until the reflected image of the brighter object comes in contact with the direct image of the less distinct object. Clamp the index bar, and, with the tangent screw, bring the two images exactly together. Note the reading of the vernier and apply the correction for the index error.

In order to have the plane of the limb in the plane of the two objects when the telescope is directed toward the less

distinct object, it may sometimes be necessary to hold the sextant upside down. In locating soundings, the measured angles should lie in planes that are almost horizontal.

EXAMPLE.—The angular distance between two objects, as measured with a sextant, reads on the vernier 35° 36′ 30″; what is the true angular distance if the index error of the sextant is: (*a*) +1′ 20″; (*b*) −1′ 40″?

SOLUTION.—(*a*) Since the vernier reading is 35° 36′ 30″ and the index error is +1′ 20″, the true angular distance is equal to 35° 36′ 30″ + 1′ 20″ = 35° 37′ 50″. Ans.

(*b*) Since in this case the index error is −1′ 40″, the true angular distance is equal to 35° 36′ 30″ − 1′ 40″ = 35° 34′ 50″. Ans.

LOCATING SOUNDINGS

RANGES

26. Preliminary Remarks.—Before starting the sounding work, the stations, triangulation points, and ranges should be carefully located. The work should be so arranged that the soundings may be made and located as rapidly as possible, especially when the area to be sounded is large, or many soundings are to be made. The position of the sun should be considered, so that clear, distinct sights may be had without interference from glare. The observer should be so stationed that while making observations the sun is not directly in his face, but preferably on his back or overhead. If practicable, the order of work should be so arranged that observations toward the west may be taken in the forenoon, and toward the east in the afternoon. In tidal waters, the range of the tide should be considered. If the difference in elevation between high and low tide is very great, sounding work should preferably begin after the tide has fallen to a level about half way between high and low tide, or after half ebb, and cease when it has risen to the same level or at half flood. Usually, however, sounding work can be done at all stages of the tide.

In all sounding operations where simultaneous measurements are to be made, the recorder and the various observers

should have watches set accurately to the same time. Soundings are usually made at regular intervals of time, but there is no fixed rule regarding this. The length of time between successive soundings will depend on the depth of the water, the method of observation, and the distance between adjacent soundings. When the soundings are located from the shore with a transit, the observations are commonly made at intervals of 1 minute. In this case, intermediate soundings may be located by interpolation. When soundings are located from a sounding boat by sextant observations, as many as three observations per minute can be made, since angles can be measured more rapidly with a sextant than with a transit.

27. Sounding Ranges.—Soundings are usually made on well-defined lines or courses whose positions are known. These lines are called **ranges.** They are usually laid out on shore and prolonged across the area of water surface to be sounded. In such cases, two points on each range are selected at which poles or other signals are placed to serve as guides to the sounding party in determining the range. These points should be a considerable distance apart, and should be carefully located in order to accurately establish the direction of the range passing through them. The point near the shore is called the **front range point,** or **front signal,** and that back from the shore is called the **back range point,** or **back signal.** The steersman determines the course of the sounding boat by sighting along the range and keeping the two range points in line.

The ranges should be laid out and arranged with reference to the extent of the area to be sounded and also the method of locating the soundings. In localities where the area to be sounded is comparatively small, the arrangement illustrated in Fig. 16 can be used. Two parallel rows of stakes, as CD and EF, are established. The stakes in each row through which the parallel ranges pass are usually spaced at regular intervals. The length of the interval or the distance between adjacent ranges will depend on the frequency with which the soundings are to be made. The distance between the front

and back range points should be such that well-defined ranges can be established by sighting from the boat to two range points in line.

In Fig. 16, the dotted parallel lines represent the sounding ranges. *A* and *B* are observation stations so situated as to offer a clear view over the area to be sounded, and preferably visible one from the other; the distance between them should be accurately determined.

This system of range lines controls the positions of the soundings, which are made on the range line and distributed over the area to be sounded in such manner as may be desired, thus avoiding unequal distribution, making two or more soundings at or near the same place, or allowing too great an interval between soundings. For such purpose, the range lines are advantageous in nearly all soundings. When a boat is on a range the observer always knows its approximate position. Soundings made on range lines are platted with greater facility than those not made on ranges. The system of range lines is especially adapted for use when the soundings are located from shore by means of angles measured with a transit at one extremity of the base line. One angle for each sounding is measured between the base line and the line of sight to the boat. Before commencing the soundings, the angles made by the range lines with the base line should be measured, and the distance along the base line from the instrument to the intersection of each range line with the base should be determined. In some cases, the soundings are located by means of two angles measured simultaneously from both extremities of the base to the sounding boat; in this case each range is used as a guide for the sounding boat and also as a check on the accuracy of the locations made on it.

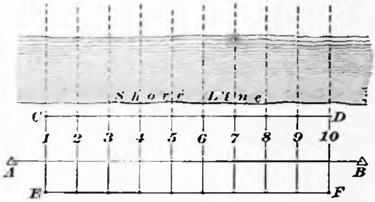

FIG. 16

28. Ranges Marked by Buoys.—If the shore is heavily wooded or rocky and precipitous, it may be impracticable to establish two rows of stakes at a sufficient distance apart to serve as front and back range points. In such a case, buoys may be used for signals to mark the front range points. Each range will then consist of a point on shore and a buoy in the water, as illustrated in Fig. 17. In this figure, *A*, *B*, *C*, and *D* are points or stations on shore, which may be located by direct measurement from point to point, while *1*, *2*, *3*, and *4* are the corresponding buoys. The buoys are located by measuring two angles in each triangle, the angles being read from the shore stations. Thus, the buoy at *1* can be located by measuring the angles *B A 1* and *A B 1*; the buoy

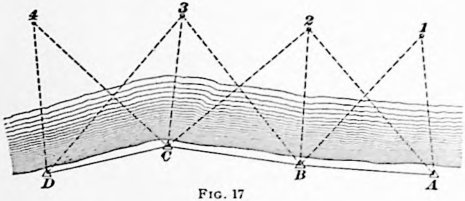

FIG. 17

at *2* by measuring the angles *A B 2* and *B A 2*, or the angles *C B 2* and *B C 2*. The buoys at *3* and *4* are located in a similar manner.

Buoys may be used for points of reference in connection with fixed points on shore. The position of each buoy will vary within small limits according to the stage of the tide, but such variations will not usually be sufficient to cause appreciable error in the platted positions of the soundings.

29. Radial Ranges.—Where topographical conditions will permit, the front range points are located close to the shore line, and some prominent natural object, such as a tall tree, a church spire, a windmill, or the cupola of a building, is selected for a back range signal. In such a case, the distance from the shore line to the back range signal should be such that radial range lines from this point

through the several front range signals will cover the area to be sounded. The distance between adjacent ranges at their extremities should not usually be greater than the average distance between successive soundings on a range. Such an arrangement is illustrated in Fig. 18. In this figure AB is a base line on which the front range points are located; these are represented by small dots. The broken lines numbered *1*, *2*, *3*, etc. are the sounding ranges. The front range points should be at known distances apart, the distance between adjacent range points being carefully measured with a steel tape, and each point marked by a stake. The points A and B at the extremities of the base line, and

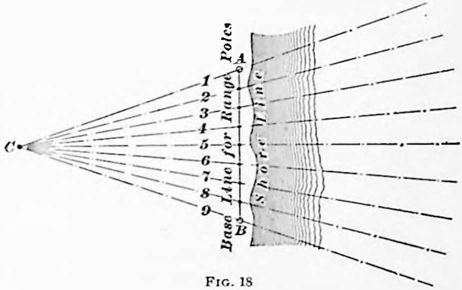

FIG. 18

the back range signal C, can be located from other points on the outline survey whose positions are known.

30. Ranges Across Streams.—When soundings are to be made across rivers or streams of considerable magnitude, sounding ranges are usually run across in directions perpendicular to the axis of the stream. Such ranges are marked by range signals placed either on one or both banks according to the width of the stream.

RANGE SIGNALS

31. Range Poles.—In designating the ranges, it is important to have the front and back range points marked by poles, or other objects, sufficiently conspicuous to be

easily visible from the sounding boat, and designated in such a manner as to distinguish the different ranges, each from the others. Such objects are called **signals**; they may consist of poles or rods, or of natural objects on the shore. When a range point is in the water, the signal marking it usually consists of a buoy, as has been previously stated. In shallow water, signals similar to those used on the shore are often used, being set on, or driven into, the bottom.

Range signals on shore usually consist of poles of suitable height and dimensions. When the sounding ranges are short, ordinary transit sight poles are frequently used for signals. In such cases an assistant holds the rod in position on the stake marking the range point, or it is placed in a vertical position by the stake.

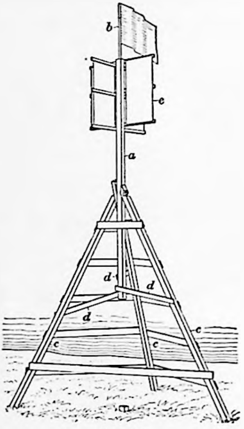

Fig. 19

If the ranges are of considerable length and soundings are to be made at some distance from shore, larger and more conspicuous poles should be used for signals. These may consist of pieces of 4″ × 4″ scantling, of suitable lengths. They should be set vertically and may be supported by being firmly driven into the ground, their lower ends being sharpened, or by being placed in holes dug for the purpose. If the ground is hard or rocky, the poles may be supported by braces or by stones piled around their bases. A form of range signal that is often used is illustrated in Fig. 19. A pole *a*, consisting of a piece of 4″×4″ scantling of suitable length and carrying a flagstaff *b* on top of it, is set in a vertical position with its bottom at any convenient height above the ground. The pole is held in position by three inclined braces, or legs *c*, which are bolted to it, and by horizontal wooden strips *d*

nailed to the pole and the legs. Other horizontal strips are attached to the legs to keep them from spreading. To make the signal more conspicuous, a crossed target *c* of wood and cloth may be nailed to the pole *a* near its upper end. This form of range signal can be set directly over a stake or hub, as shown in the illustration.

Range poles should be whitewashed so as to be conspicuous against the background of the shore. When a number of adjacent ranges are used, they may be designated by attaching colored flags to the poles or signals. In such cases each range is known by some distinctive color or combination of colors. Thus, the flag for range No. *1* may be red; that for range No. *2*, red and white, etc.

FIG. 20

Ranges are sometimes designated by strips of wood, such as laths or barrel staves, nailed to the poles or signals. The strips should be arranged in the form of Roman numerals, as shown in Fig. 20. In such cases the numerals denote the numbers of the ranges; the arrangement shown in Fig. 20 represents range No. *6*. The strips and the pole should be whitewashed so as to be conspicuous.

FIG. 21

32. Targets.—When sounding ranges are to be projected a considerable distance from shore, the range poles or signals should be provided with targets in order to be conspicuous. Such targets should be sufficiently large to be visible from the sounding boat at the most distant point on the range, and of suitable designs or colors to enable the steersman to distinguish readily the different ranges. No rigid rule can be laid down specifying any particular form or design for range targets. They may be made of such forms as are best suited for the purpose, and composed of such materials as are available in each case.

A good form of target for range signals is shown in Fig. 21. The target is lozenge shaped and can be made in the following manner: A strip of wood, about 3 inches wide, 1 inch thick, and 3 feet long, is nailed to the face of the range pole about 3 feet below the top, care being taken to center the strip and to make it perpendicular to the pole. To the framework thus formed, a square piece of white or colored cloth is tacked in such a manner that two diagonally opposite corners of the cloth are at the two extremities of the cross-piece, the two other corners being on the center line of the range pole. Such a target is quickly and economically made and is very effective when the sights are directly in front and the full size of the target is visible.

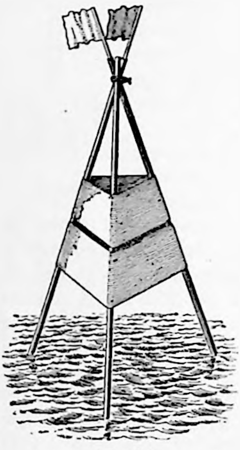
FIG. 22

33. Range Signals in the Water.—When a range point is in the water, the signal marking it usually consists of a buoy; in shallow water, however, stationary range signals are often used. A form of signal used by the United States Coast and Geodetic Survey is shown in Fig. 22. This consists of a tripod about 10 or 12 feet high, each leg being made of a piece of gas pipe about $1\frac{1}{2}$ inches in diameter. The legs are forced firmly into the mud or sand of the bottom, at suitable distances apart, and inclined toward the center. They are lashed together near the top, and flags about $1\frac{1}{2}$ feet square attached to poles just large enough to fit inside the pipes are placed at their upper ends as shown. Two strips of cloth, each about $\frac{1}{2}$ yard wide, are wrapped around the tripod, about half way between its top and bottom. These strips serve as a target.

34. Buoys.—A buoy is a float of wood or other suitable material, or a hollow air-tight vessel, anchored in place by a heavy weight to which it is attached by a rope or chain. Buoys are used to mark certain places or points on the water surface. They are usually employed to designate the limits of a channel or some submerged object in connection with navigation. They are also used as points of reference and for range points in hydrographic surveying, and only such as are suitable for such purposes will be considered here.

A form of buoy that has been much used in hydrographic surveying is illustrated in Fig. 23. It consists essentially of a round log of cedar or other light wood, about 1 foot in diameter and 3 feet in length, sawed square at ends. The lower half is trimmed in the shape of a truncated cone, tapering to about 5 inches in diameter at the lower end. A hole about 2 inches in diameter and 9 inches deep is bored into the lower end on the axis of the log, into which a pole 2 inches in diameter is driven. The upper end of the pole is split, and a wedge inserted in the cleft, which is driven up and tightens the pole as it is driven to the end of the socket, thus preventing the pole from pulling out. A hole sufficiently large for the anchor rope to pass through is bored through the pole a few inches above its lower end. The anchor rope is preferably of manila hemp and is about 1 inch in diameter. A good form of knot with which to tie the rope is shown in the figure; it is shown open in order to illustrate the method of forming the knot. This knot is called the **two half-hitches.** A hole about 2 inches in diameter and 10 inches deep is bored into the top of the buoy along its axis. This serves as a socket into which is inserted a staff

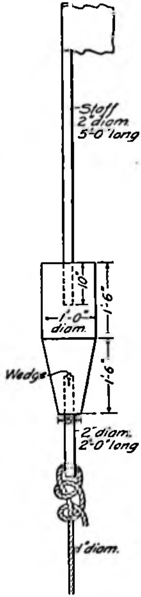

FIG. 23

about 2 inches in diameter and 5 feet long. At the upper end of this staff is fastened a flag about 1 foot square and of suitable design or color.

Another form of buoy is illustrated in Fig. 24. This consists of a log or round piece of light wood, about 3 feet long, sawed square at both ends. This log is trimmed in the shape of a truncated cone, tapering from about 8 or 10 inches in diameter at the upper end to a diameter of about 4 or 5 inches at the lower end. A hole about 2 inches in diameter is bored completely through the log, the center of the hole coinciding with the axis of the log, and a round pole large enough to fit the hole closely is passed through the log and wedged tightly in place. This pole should project about 2 or 3 feet below the bottom of the log or buoy and about 3 or 4 feet above its top. A flag about 1 foot square is fastened to the upper end of the pole as shown. The anchor rope is passed through a hole in the pole near its lower end and tied as described in the preceding article.

Fig. 24

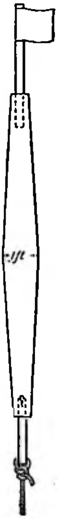

Fig. 25

35. Buoys for Tidal Waters.—The two forms of buoys just described are suitable for use in non-tidal waters and in rivers and streams where the current is not sufficiently strong to drag the top of the buoy under or level with the surface of the water.

Buoys for use in tidal waters should be of sufficient length to be visible at all stages of the tide. The best length for a buoy in a given tidal water will depend on the range of the tide, and is usually greater than that required for buoys in non-tidal waters.

A good form of buoy for use in tidal waters is illustrated in Fig. 25. The length shown is 10 feet, but this may be varied to conform to the range of the tide. The buoy is

made from a log or round piece of light wood and trimmed so as to taper gradually from the middle to each end. It has a diameter of about 1 foot at the middle and tapers to a diameter of from 4 to 6 inches at each end. It is sawed square at the ends, and holes are bored at each end, into which poles are inserted for attaching the flag and anchor rope, as previously described. If preferred, a ring may be fastened to the lower end of the buoy by means of a staple or screw, and used for securing the anchor rope to the buoy.

A more simple form of buoy, consisting of a single stick or log of timber of suitable length and diameter, is often used in tidal waters; the shape is similar to that illustrated in Fig. 25, but the buoy is more uniform in size from top to bottom. Such buoys are commonly called **spar buoys.**

METHODS OF LOCATING SOUNDINGS

36. Methods Employed.—In order to plat soundings correctly on a map or chart, the position of each sounding must be located; that is, its relative position with respect to known points on shore must be determined. Soundings can be located by various methods, depending on local conditions, the object of the survey, and the degree of accuracy required. The following list comprises the best known and most frequently used methods of locating soundings: (1) by time intervals; (2) by one angle measured on shore; (3) by two angles measured simultaneously on shore; (4) by two angles measured in the sounding boat; (5) by transit and stadia; (6) by a fixed line marked by a wire or rope; (7) by the intersection of fixed ranges. These methods will be described in order.

37. By Time Intervals.—When this method is employed, the soundings are made at stated intervals of time while the sounding boat moves at uniform speed along a range or on a course not marked by range signals. The soundings may be made under two conditions, namely: (*a*) The first and last soundings on a range or course are located by observation and all the intermediate soundings are

located by interpolation or time intervals. (*b*) Alternate soundings or those made at convenient intervals are located by observation, and such intermediate soundings as are not observed are located by interpolation. In either case the method of interpolating the intermediate soundings is the same. Knowing the distance between the two end soundings or between two adjacent observed soundings, the time interval between them, and the time interval between consecutive soundings, the position of each intermediate sounding can be determined by proportion as follows:

Let T = time elapsed between two observed soundings;
D = distance between these observed soundings;
t = time interval between consecutive soundings;
d = distance between consecutive soundings.

Then, if the boat moves at a uniform speed,

$$D : T = d : t$$

from which

$$d = \frac{D\,t}{T}$$

However, since the speed of the boat is likely to vary, this method of locating soundings is not very accurate.

EXAMPLE.—A sounding boat moving at a uniform speed traverses a range 1,800 feet long in 20 minutes, and a sounding is made at each end of the range and at intervals of 1 minute; what is the distance between consecutive soundings?

SOLUTION.—The two end soundings are 1,800 ft. apart = D; the elapsed time between them is 20 min. = T; and the time interval t between consecutive soundings is 1 min. Substituting these values in the formula gives,

$$d = \frac{1{,}800 \times 1}{20} = 90 \text{ ft. Ans.}$$

EXAMPLES FOR PRACTICE

1. A range 500 feet long is traversed at uniform speed in 10 minutes by a sounding boat from which soundings are made at intervals of ½ minute; find the distance between any two consecutive soundings.
Ans. 25 ft.

2. In the preceding example, if the soundings are numbered consecutively 1, 2, 3, etc., from beginning to end of the range, what is the distance between soundings Nos. 5 and 12? Ans. 175 ft.

3. Soundings are made at intervals of 15 seconds or at the rate of 4 per minute, from a boat moving along a course at a uniform speed; the soundings made at the end of each minute are located by observations and the intermediate soundings are interpolated. The observed soundings, when located, are found to be at intervals of 201 feet apart; what is the distance between consecutive soundings? Ans. 51 ft.

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38. By One Angle Measured on Shore.—When this method is used, the boat containing the sounding party traverses a fixed range while an observer on shore measures the angle between a base line and the line of sight to the leadsman at the time a given sounding is made. The ranges are usually parallel to each other and are preferably at right angles to the base line. They should be at known distances apart and the distance from the observation station to each range should be determined by careful measurement along the base line. The base line may have an observation station at each extremity, in which case the observer is stationed at either end, as may be most convenient, and orients his instrument

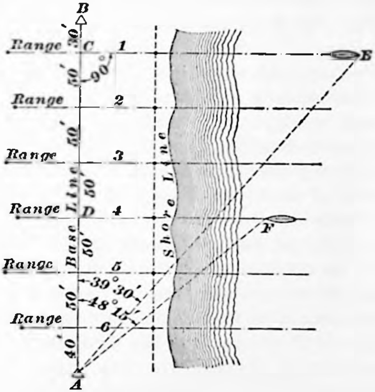

Fig. 26

by sighting toward the station at the other end. In Fig. 26 is shown a base line at the ends of which are two observation stations A and B, whose positions have been determined. The ranges numbered *1*, *2*, *3*, etc. are parallel to each other and at right angles to the base line. Each range is designated by front and back range signals whose positions are shown by the small dots in the figure. The

distances along the base line between the observation stations and the nearest ranges and the distances between adjacent ranges are as shown by the figures.

The field party usually consists of the observer on shore, and in the boat the recorder, the leadsman, the signalman, and the boat crew. In tidal waters, a tide-gauge reader should be added to the shore party; his duties consist in reading the tide gauge every 5 minutes during sounding operations and recording the times and gauge readings. The watches of the observer on shore and the recorder in the boat are set accurately to the same time. The sounding boat traverses the ranges in succession and soundings are made at regular intervals of time, which depend on the depth of the water and on the accuracy required. Usually, from one to four soundings are made per minute. A few seconds before the end of each interval the recorder has the signalman raise his flag, and exactly at the end of the interval the flag is lowered, as a signal to the observer that the sounding has been made. The leadsman calls out the observed depth of each sounding to the recorder, who enters it in his notebook together with the number of the sounding. The exact time of each sounding is recorded. The character of the bottom is observed by the leadsman and noted by the recorder at such intervals as may be required.

The observer is stationed at *A* with his transit set up over the transit point at that end of the base line. The vernier of the transit is first set at zero and the telescope is directed toward *B*, the point at the other end of the base line, and the instrument is clamped. The upper plate is then unclamped and the observer turns the instrument in azimuth toward the sounding boat. When making the observations, the observer usually keeps his watch open and lying face uppermost on the upper plate of the transit, for convenience in noting the time. When the signal flag is raised in the boat the observer sights through the telescope toward it, and by turning the upper plate slowly and carefully, keeps the line of sight fixed on the flag. At the instant the flag is lowered the observer ceases to turn the plate. He notes the exact

time and reads the angle on the plate and enters the number of the sounding, the time, and the angle in his notebook. The observations are usually made on the flag, as it can be seen more distinctly and at greater distances than a sounding line or pole. On this account the signalman should be stationed near the leadsman, so that the difference between the observed and the true position of each sounding will be small. The upper plate of the transit should remain unclamped while observations are being made on the sounding boat, since there is usually not sufficient time between observations to permit its being clamped. Also, frequent clamping and unclamping would tend to disturb the position of the transit and thus may introduce errors in the observed angles.

In some instances, there is at each transit station a recorder in addition to the observer, and it is the duty of the recorder to enter in the notebook the observations called out to him by the observer. Thus, he records the number of each sounding, the time it was made, and the observed angle. Furthermore, it is customary for the signalman to raise a red flag for every fifth sounding and a white flag for the intermediate soundings. Whenever the observer sees the red flag displayed by the signalman he calls out "red" to the recorder, who then notes the number of the sounding, which should be a multiple of five, in order to correspond with the number entered by the recorder in the boat. In this way a check is obtained on the numbering of the soundings, and any difference in the numbering by the recorder in the sounding boat and the recorder on shore can be readily detected.

EXAMPLE.—The ranges shown in Fig. 26 are at right angles to the base line; a sounding is made while the sounding boat is at E on range *1*. The observed angle $E A B$ is 39° 30′ and the distance $A C$ along the base line from A to the intersection C of range *1* is 290 feet; find: (*a*) the distance $A E$; (*b*) the distance along the range line from C, its intersection with the base line to the sounding at E.

SOLUTION.—(*a*) Since the ranges are at right angles to the base line, $A E$ is the hypotenuse of the right triangle $A C E$. From trigonometry,

$$A E = \frac{A C}{\cos E A C} = \frac{290}{\cos 39° 30'} = 375.8 \text{ ft.} \quad \text{Ans.}$$

(*b*) The distance from E along range *1* to its intersection C with the base line is $EC = AC \tan EAC = 290 \tan 39° 30' = 239.1$ ft., nearly. Ans.

EXAMPLES FOR PRACTICE

1. The distance AD along the base line from A to the intersection of range *4*, Fig. 26, is 140 feet; the angle FAB is 48° 15′; find: (*a*) the distance AF; (*b*) the distance along the range from F to its intersection D with the base line. Ans. $\begin{cases} (a)\ 210.2 \text{ ft.} \\ (b)\ 156.9 \text{ ft.} \end{cases}$

2. A sounding boat is on a range perpendicular to the base line. The angle measured at an observation station between the base line and the line of sight to the boat at the time a given sounding is made is 30° 30′; the distance from the station to the intersection of the base line and range is 230 feet; find: (*a*) the distance from the station to the position of the sounding; (*b*) the distance along the range line from the base line to the position of the sounding. Ans. $\begin{cases} (a)\ 266.9 \text{ ft.} \\ (b)\ 135.5 \text{ ft.} \end{cases}$

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39. By Two Angles Measured Simultaneously on Shore.—This is one of the commonest methods, and if the work is carefully done it is both convenient and accurate. Two observers are required, each occupying a station whose position with respect to the shore survey has been determined. The observation stations should be so situated as to afford a clear field of view over the area to be surveyed, and when possible should be visible one from another. They may be at the extremities of a base line, whose length has been carefully measured, or at two points whose positions and distance apart have been determined by triangulation. The vernier of each instrument is set to read zero when the telescope is directed toward the other instrument point or toward some common point whose position is known. The field work is entirely similar to that described for the preceding method, and the field party and equipment is the same with the addition of an observer and transit. This method differs from the preceding method, however, in that two angles, instead of one, are measured for each location, the observations being made simultaneously, and the position of the observed sounding is determined by the intersection of the two lines of sight from the two observation stations.

instead of by the intersection of one line of sight with a range line. In using this method it is not necessary to have the sounding ranges parallel or to lay them out at right angles to the base line, although such an arrangement is advantageous in affording a means of checking the accuracy of the angular measurement. For locating soundings over a limited area by this method, the arrangement shown in Fig. 27 is convenient and gives good results. In this figure, A and B are the observation stations at the extremities of a base line $A\,B$. The ranges are shown by the parallel lines passing through the small dots indicating the range signals. One position of the sounding boat is shown at C, and the lines of sight to this position from the two observation stations are represented by the dotted lines $A\,C$ and $B\,C$.

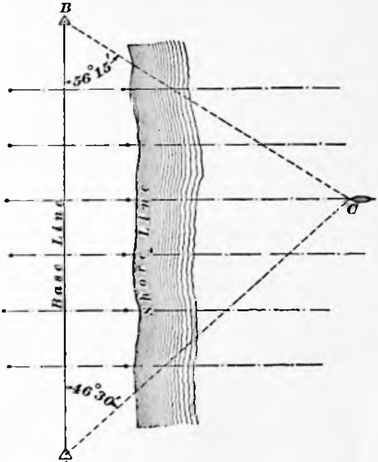


Fig. 27

Example.—A sounding is made while the sounding boat is at the position C, Fig. 27. The angles observed from A and B are 46° 30′ and 56° 15′, respectively, as shown, and the length of the base line $A\,B$ is 785 feet; find the distances $A\,C$ and $B\,C$, giving values to the nearest foot.

Solution.—The angle $B\,A\,C = 46° 30'$, and $A\,B\,C = 56° 15'$; hence, $A\,C\,B = 180° - (46° 30' + 56° 15') = 77° 15'$, and, from trigonometry,

$$A\,C = \frac{A\,B \sin A\,B\,C}{\sin A\,C\,B} = \frac{785 \sin 56° 15'}{\sin 77° 15'} = 669 \text{ ft.} \quad \text{Ans.}$$

$$B\,C = \frac{A\,B \sin B\,A\,C}{\sin A\,C\,B} = \frac{785 \sin 46° 30'}{\sin 77° 15'} = 584 \text{ ft.} \quad \text{Ans.}$$

40. By Two Angles Measured in the Sounding Boat.—This method, which is used extensively in harbor work, is one of the best general methods of locating soundings. The field party usually consists of two observers, a recorder, a leadsman, and boat crew. In tidal waters a tide-gauge reader is required. The observers, each with a sextant, occupy places in the sounding boat as close to the leadsman as practicable, in order that the observed position of each sounding may be very nearly the same as its true position. At the time a sounding is made, the two observers measure simultaneously the two angles between the lines of sight to three shore objects whose positions have been determined by the shore survey, one line of sight in each observation being directed toward the same object. The objects sighted to should be well defined and prominent, and so located with respect to the area to be sounded as to be readily visible from the sounding boat in all required positions. They should preferably be natural objects, such as church spires, windmills, lighthouses, cupolas, etc., but in case natural objects are not available, signal poles, such as are used for marking ranges, may be used. In making the observations, one observer measures the angular distance between the middle object and the object on the right; and the other observer measures the angular distance between the middle object and the object on the left. This is illustrated in Fig. 28, in which F represents the position of the boat at the time of a given sounding, and A and B are the two angles measured by the two observers between the lines of sight to the three shore objects E, C, and D. The sounding work is conducted as follows:

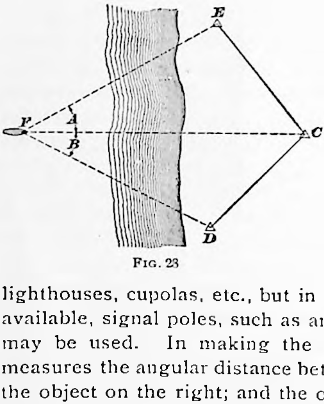


Fig. 28

The sounding boat moves slowly along a range or course, the leadsman making the soundings at the required intervals,

usually two or three per minute. A few seconds before a sounding is to be made the leadsman calls out "ready," when the observers hold their sextants in position to make an observation on the shore objects, each observer moving the vernier arm of his sextant so as to keep the two images in coincidence as the boat moves. At the moment the sounding is made, the leadsman calls out "sound," when each observer reads the angle on his sextant and calls it out to the recorder, who records each angle in its proper column in his notebook. The leadsman calls out the observed depth to the recorder, who also enters it in his notebook, together with the number of the sounding and the time the sounding is made. At required intervals, the leadsman observes the character of the bottom and informs the recorder, who enters it in the proper place in his notebook.

In some cases both angles are measured by one observer with a double sextant; they can also be measured successively by one observer with an ordinary sextant, if the boat is brought to a stop for each sounding. But they are usually measured by two observers, each using an ordinary sextant, in the manner just described. When sextants are used and the angles are so recorded by the recorder that the observer has only to observe and read them, four angles per minute can be observed under ordinary favorable conditions.

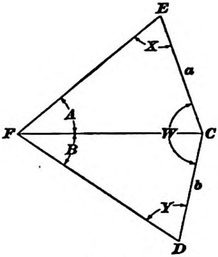


FIG. 29

41. The accurate location of soundings by two sextants involves what is known as the **three-point problem.** This problem can be solved trigonometrically as follows: Let F, Fig. 29, be the position of the boat when a given sounding is made; E, C, and D the three shore objects, whose positions are determined by the angle W and the sides $E\,C$ and $C\,D$, which are designated by a and b, respectively. The angles A and B are the two sextant angles measured in the boat. The problem is to determine the distances $F\,E$ and $F\,D$.

In the triangles EFC and CFD, Fig. 29 or 30,

$$CF = \frac{a \sin X}{\sin A} = \frac{b \sin Y}{\sin B} \qquad (a)$$

Also, $X+Y+W+A+B=2\times 180°=360°$

Therefore, if S represents the sum of X and Y,

$$S = X+Y=360°-(W+A+B) \qquad (b)$$

and

$$Y=S-X \qquad (c)$$

Then, $\sin Y=\sin (S-X)=\sin S \cos X-\cos S \sin X$

If this value of $\sin Y$ is substituted in equation (a),

$$\frac{a \sin X}{\sin A} = \frac{b (\sin S \cos X - \cos S \sin X)}{\sin B}$$

and, if the parenthesis is removed and the fractions are cleared, the equation becomes

$$a \sin X \sin B=b \sin S \cos X \sin A-b \cos S \sin X \sin A$$

If both sides of this equation are now divided by $\sin X$, $\frac{\cos X}{\sin X}$ is replaced by $\cot X$, and $\cot X$ is solved for, the equation obtained is

$$\cot X = \frac{a \sin B + b \cos S \sin A}{b \sin S \sin A} = \frac{a \sin B}{b \sin S \sin A} + \frac{\cos S}{\sin S}$$

Therefore,

$$\cot X = \frac{a \sin B}{b \sin S \sin A} + \cot S \qquad (d)$$

The value of Y can be determined either similarly or by substituting the value of X in equation (c). After the values of X and Y are determined, the distances EF and DF can be found by trigonometry. In triangle EFC,

$$ECF = 180° - (A + X) \qquad (e)$$

$$EF = \frac{a \sin ECF}{\sin A} \qquad (f)$$

Similarly, in the triangle CFD,

$$DCF = 180° - (B + Y) \qquad (g)$$

$$DF = \frac{b \sin DCF}{\sin B} \qquad (h)$$

After the distances EF and DF for a given sounding are calculated, the position of the sounding can be located by drawing arcs with a pair of compasses, with E and D as centers and with radii of lengths EF and DF, respectively. The intersection of the two arcs will be the point F, or the

position of the sounding. When a rock, a reef, a buoy, or other important object is located by sextant angles to three fixed points on shore, the location should be calculated. However, the positions of soundings located by this method may be platted fairly accurately without calculation, as explained later.

EXAMPLE.—In Fig. 29, a = 850 feet, b = 760 feet, W = 150°, A = 41° 30′, and B = 35°30′. Calculate the distances $E\,F$ and $D\,F$.

SOLUTION.—If equation (b) is applied, $S = X + Y = 360° - (W + A + B) = 133°$. Then, by equation ($d$),

$$\cot X = \frac{850 \sin 35°30'}{760 \sin 133° \sin 41°30'} + \cot 133°$$

But, $\sin 133° = \sin (180° - 133°) = \sin 47°$, and $\cot 133° = -\cot (180° - 133°) = -\cot 47°$. Hence,

$$\cot X = \frac{850 \sin 35°30'}{750 \sin 47° \sin 41°30'} - \cot 47° = 1.34021 - 0.93252 = 0.40769$$

Then, $X = 67°49'$; and, by equation (c), $Y = 133° - 67°49' = 65°11'$.

By equations (e) and (f) for triangle $E\,F\,C$,

$$E\,C\,F = 180° - (41°30' + 67°49') = 70°41'$$

$$E\,F = \frac{850 \sin 70°41'}{\sin 41°30'} = 1{,}211 \text{ ft. Ans.}$$

Also, by the equations (g) and (h) for triangle $C\,F\,D$,

$$D\,C\,F = 180° - (35°\,30' + 65°\,11') = 79°\,19'$$

$$D\,F = \frac{760 \sin 79°\,19'}{\sin 35°\,30'} = 1{,}286 \text{ ft. Ans.}$$

EXAMPLES FOR PRACTICE

1. In Fig. 30, in which F is the position of the sounding boat at the time a given sounding is made, and E, C, D are the three shore points, let a = 1,200; b = 965; W = 146° 30′; A = 28° 15′; and B = 22° 30′; find the angles X and Y and the distances $E\,F$ and $D\,F$.

$$\text{Ans.} \begin{cases} X = 80°\ 21' \\ Y = 82°\ 24' \\ E\,F = 2{,}403 \\ D\,F = 2{,}437 \end{cases}$$

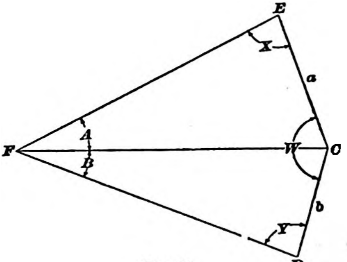


FIG. 30

2. With the same values for a, b, and W, let A = 30°

30′ and $B = 24° 28′$; find the angles X and Y and the distances EF and DF.

$$\text{Ans.}\begin{cases} X = 77° 3′ \\ Y = 81° 29′ \\ EF = 2{,}254 \\ DF = 2{,}240 \end{cases}$$

---

42. By Transit and Stadia.—This is a rapid and efficient method of locating soundings in bodies of calm, smooth water and at distances that do not exceed the limit of good practice for stadia readings. In this method, the positions of the soundings are located with a transit on shore by means of observations taken on the stadia rod held in the sounding boat. Since the stadia rod should be without vertical motion when a reading is taken, it is evident that this method can be used satisfactorily only on smooth water. When this method for locating soundings is used, a complete hydrographic party comprises the observer on shore, with a transit equipped with stadia wires, and the boat party, consisting of the recorder, the leadsman, the stadiaman, and the boat crew. No signalman is required; the recorder acts as signalman. The soundings are not identified by time intervals, but by means of differently colored flags. A red flag is shown for every fifth sounding and a white flag for the intermediate soundings. Two general cases may occur under this method.

1. The transit station may be a point on the sounding range; in this case the azimuth of the range is known and each sounding is located by the distance, corresponding to the observed interval on the stadia rod, as measured along the range.

2. The transit station may be a point whose position has been determined but which is not on a sounding range; in this case the reading of the azimuth angle, as well as the stadia interval, must be observed and recorded for each sounding.

In either case the field work is conducted in the following manner: The sounding boat moves slowly along the range or course while the soundings are being made. The leadsman stands in the bow of the boat and makes the soundings,

calling out the observed depth of each sounding and also the character of the bottom at required intervals. The recorder enters in his notebook the number and the observed depth of each sounding, and the character of the bottom when noted by the leadsman. If the soundings are in tidal waters, the time should also be noted in order to make reductions for the tide heights as given in the notebook of the tide-gauge reader. During the sounding operations, the stadiaman holds the stadia rod vertical and facing the observer. He should be stationed close to the leadsman, in order that the observed positions of the soundings will coincide nearly with their true positions.

The observer keeps the vertical wire of the transit telescope directed to the stadia rod in the boat. If the transit station is on the range on which the soundings are made, the observer merely reads the stadia interval for each sounding and enters it in his notebook, also noting the time and the number of the sounding. If the transit station is not on the sounding range, but is off to one side, the vernier of the transit is first set at zero, the telescope is sighted on some object whose position has been determined, and the instrument is clamped. The upper plate is then unclamped, and the instrument turned in azimuth toward the sounding boat as explained for the second method. Then, for each sounding, the horizontal angle is read and recorded, in addition to the stadia interval, and the number and time of the sounding.

43. By a Fixed Line Marked by a Wire or Rope. This is an accurate method, but it is adapted only to narrow channels. It is often used for measuring cross-sectional areas in a canal or a small stream in connection with the determination of discharge or the measurement of material removed from the channel by dredging or other means. In such cases the wire or rope is stretched from bank to bank between fixed points, as illustrated in Fig. 31, and the soundings are taken at regular intervals along the wire or rope. The points where the soundings are taken are marked

by tin tags or by bits of cloth tied to the wire or rope. When this method is employed in connection with the measurement of dredged material, the stakes O, O' are carefully located and their positions noted, in order that they may be replaced if disturbed. Soundings are made at

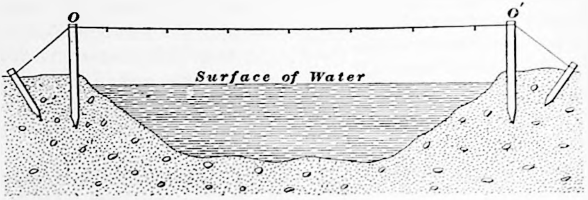


FIG. 31

known intervals along a wire or rope stretched from stake to stake, before and after the dredging operations.

44. By the Intersection of Fixed Ranges.—If a fixed range or section of considerable length is to be sounded a number of times, and the soundings are to be made at the same points each time, the soundings can be located by the

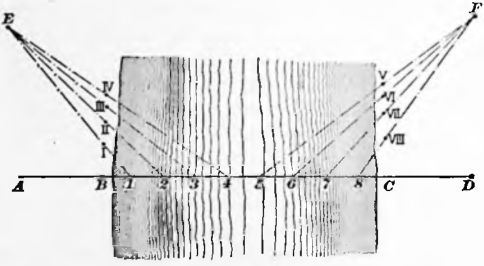


FIG. 32

intersection of a series of ranges with the fixed range or section. Let $A D$, Fig. 32, represent a range or section across a river, and *1, 2, 3, 4, 5, 6, 7, 8* the points where soundings are to be made at successive periods. Range poles are set at A, B, C, and D, fixing the position of the range $A D$, unless

those points are marked by natural objects, and poles are also set at *E* and *F*; also at *I*, *II*, *III*, *IV*, etc. The ranges *E–I*, *E–II*, etc. and *F–V*, *F–VI*, etc., produced to their intersection with the range *A D*, will locate the soundings *1*, *2*, etc., and *5*, *6*, etc. The range signals *A*, *B*, *C*, *D*, and the back signals *E* and *F* for the numbered ranges may consist of ordinary range poles, whitewashed, as described in Art. **31.** The front range signals *I*, *II*, *III*, *IV*, *V*, etc., on the numbered ranges, should be designated by Roman numerals indicating the number of each range, as described in Art. **31.**

When this method is used, the sounding party consists of a recorder, a leadsman, and boat crew. The steersman keeps the boat on the fixed range *A D*, and each sounding is made when the leadsman, by sighting toward a numbered signal, finds himself in range with it and the back signal at the same time he is in line with the signals designating the range *AD*. Thus, when at the position *5*, Fig. 32, the leadsman is in line with the signals *C D*, designating the range *A D*, and also with the signals *V F*, designating range *V*. The boat can be stopped for each sounding if there is little or no current; or if the current is strong, the boat can move slowly, preferably against the current.

45. The Plane of Reference.—In making soundings, the leadsman notes the depth of each sounding below the water surface at the time the sounding is made. Since the elevation of the water surface is constantly changing, especially in tidal waters, it is necessary to select some particular stage or height of the water surface to which the depths of all the soundings are referred. Such a height of the water surface is called a **plane of reference**, and all observed depths are reduced to correspond to depths below this surface. In order to determine the proper reductions to apply to the soundings for different stages of the tide, it is necessary to know the elevation of the water surface at any given time during the sounding work; for this reason it is customary to employ a tide-gauge reader. In tidal waters, the surface of the water at mean low tide is usually taken as the

plane of reference, and the tide gauge should be set with the zero mark at the elevation of mean low tide. In such cases tide-gauge readings should be taken and recorded every 5 minutes during sounding operations, as has been explained. In lakes or reservoirs, where the elevation of the water surface changes but little and very slowly, the lowest recorded stage of the water is usually selected as the plane of reference. In such cases it is customary to take gauge readings twice a day—once in the morning and once in the afternoon during the period of sounding work. In rivers of variable stage, the plane of reference is usually the low-water stage of the river at the locality where the sounding work is done. In some cases, the general datum of the survey is used as a plane of reference. If the river is rising or falling rapidly while the soundings are being made, gauge heights should be read and recorded at intervals of 30 minutes, or even oftener if necessary. If, however, the river is at its normal stage during this period, and is changing but slowly, gauge readings should be taken twice a day, as for lakes or reservoirs.

FORMS FOR SOUNDING NOTES

46. Sounding Book.—For keeping the field notes of sounding work, three forms of field books are used; these are called, respectively, **sounding book, tide book,** and **angle book.** The sounding book, the form for which is shown in Form 1, is used by the recorder in the sounding boat. The first three columns contain, respectively, the number, the time, and the observed depth for each sounding; this information is obtained and entered by the recorder while in the sounding boat. The next two columns contain the reduction for tide and the reduced depth for each sounding; these are filled out in the office from the data obtained from the tide book, if the soundings are made in tidal waters. If the soundings are not made in tidal waters, no reductions are needed and these two columns are left blank. In the column headed Remarks should be entered the information obtained by the leadsman relative to the

character of the bottom, and also such information about the sounding ranges, the intervals between successive soundings, etc., as may be desirable. If a lead line is used in making the soundings, any errors in its length should be noted in this column, in order that proper corrections may be made to the observed depths.

FORM 1—SOUNDING BOOK

Soundings off Cape Charles
June 10, 1903

Johnson, Recorder
Kennedy, Leadsman

No.	Time	Soundings Feet	Reduction for Tide	Reduced Soundings Feet	Remarks
1	10:30	4.2			Range 13.
2		5.2			Soundings num-
3	10:31	8.2			bered west from
4		7.2			shore and made at
5	10:32	3.7			½-minute intervals.
6		3.3			Flag dropped at
7	10:33	3.8			1-minute intervals.
8		4.3			Bottom from sound-
9	10:34	2.8			ing No. 1 to 5, sand;
10		3.3			No. 6 to 8, shells.

47. Tide Book.—The tide book, shown in Form 2, is used by the tide-gauge reader; it contains the readings of the tide gauge at regular intervals of time and the time that each reading is taken. The direction and force of the wind also are usually noted and entered. From these notes, the proper reduction for tide can be obtained for each sounding, and the soundings can all be reduced to the plane of reference.

48. Angle Books.—Forms 3 and 4 show the form for the angle book that is used by the transit or sextant observer to record the angular measurements made in locating the

soundings. In the field he enters in the angle book the time and the observed angle for each sounding to be located. These are entered in the second and third columns, respectively, the first column being left blank until the observer obtains from the sounding book the numbers corresponding to the times of the observed soundings. Each observer is provided with an angle book in which he enters the field notes in the manner described. When the soundings are

FORM 2—TIDE BOOK

Observations of Tides at Cape Charles Gauge
June 10, 1903 J. Mason, Observer

Mean Time of Observation		Reading of Staff Gauge	Wind		Remarks
Hours	Min.	Feet	Direction	Force	
10	30	1.2	N W	Moderate	Gauge fastened to
10	35	1.3			pile at S. E. corner
10	40	1.4			of lighthouse wharf.
10	45	1.5			Tide rising.
10	50	1.6	W		Zero of gauge at
10	55	1.7			mean low water.
11	00	1.8			

located by time intervals and no angular measurements are made, the sounding book constitutes a complete office record of the soundings after the tide-gauge readings are obtained from the tide book and the reductions for the soundings have been entered.

49. Office Record.—When soundings are located by transit or sextant angles, a complete office record is obtained by combining the field notes in the manner shown in Form 5. The notes there shown are those given in Forms 1, 2, 3, and 4.

Form 3—Angle Book

Survey of Channel off Cape Charles, June 10, 1903
Observer No. 1, R. Briggs
Young & Sons' Transit No. 1612

No.	Time	Angle	Object Observed	Station Occupied	Remarks
1	10:30	41° 18′	Signal flag on launch	Transit Sta. A, at S.	Instrument set with vernier at
3	10:31	45° 00′		end of base line	zero when telescope points
5	10:32	49° 00′		on Cape Charles.	to Sta. B. Angles read to
7	10:33	54° 33′			the left from A–B. Sound-
9	10:34	61° 05′			ings on range 13, beginning
					at shore and running west.

Form 4—Angle Book

Survey of Channel off Cape Charles, June 10, 1903 Observer No. 2, J. Smith, Buff & Berger Transit No. 2840					
No.	Time	Angle	Object Observed	Station Occupied	Remarks
1	10:30	43° 05′	Signal flag on launch	Sta. B on E. side of	Vernier at zero when telescope
3	10:31	49° 27′		entrance to bay,	points to Sta. A. Angles
5	10:32	57° 15′		opposite light-	read to right. Soundings on
7	10:33	64° 42′		house.	range 13, beginning near
9	10:34	73° 05′			shore and running west.

Form 5—Office Record

Survey of Channel off Cape Charles, June 10, 1903 C. F. Johnson, Recorder T. Kennedy, Leadsman						Observer No. 1, Briggs, on Sta A, zeros on Sta B Observer No. 2, Smith, on Sta. B, zeros on Sta. A		
No.	Time	Soundings Feet	Reduced for Tide	Reduced Soundings Feet	Character of Bottom	Angles and Ranges		Remarks
						No. 1, Range 13	No. 2, Range 13	
1	10:30	4.2	1.2	3	Sand	41° 18′	43° 05′	
2		5.2	1.2	4				
3	10:31	8.2	1.2	7		45° 00′	49° 27′	
4		7.2	1.2	6				
5	10:32	3.7	1.2	2½	Sand	49° 00′	57° 15′	
6		3.3	1.3	2	Shells			
7	10:33	3.8	1.3	2½		54° 33′	64° 42′	
8		4.3	1.3	3	Shells			
9	10:34	2.8	1.3	1½		61° 05′	73° 05′	
10		3.3	1.3	2				

FORM 6

Survey of Midland Canal May 2, 1901				Johnson, Inst. Williams, Rod. Jones, Taylor } Assistants Gurley Level No. 2916
Sta.	Eleva.	Elevation of Water Surf	Remarks	Soundings
128	52.0	50.0	The water surface is used as the plane of reference.	$\frac{0.0}{2.0}$ $\frac{3.0}{5.0}$ $\frac{6.0}{10.0}$ $\frac{6.5}{13.0}$ $\frac{6.8}{18.0}$ $\frac{6.2}{28.0}$ $\frac{7.4}{38.0}$ $\frac{4.0}{44.0}$ $\frac{0.0}{48.0}$
129	52.5	50.0	Numerator equals the depth, in feet. Denominator equals the dist. from sta.	$\frac{0.0}{3.0}$ $\frac{3.0}{6.0}$ $\frac{6.5}{12.0}$ $\frac{7.0}{16.0}$ $\frac{7.4}{20.0}$ $\frac{6.3}{30.0}$ $\frac{7.0}{39.0}$ $\frac{3.0}{46.0}$ $\frac{0.0}{49.0}$
			Distances measured from left to right.	

50. Form 6.—When soundings are located by means of a wire or rope stretched across the stream, the field notes may be kept in the manner shown in Form 6. The notes there given represent sounding measurements across a canal at Stations 128 and 129 of the shore survey or traverse along the canal bank. The left-hand page of the notebook contains the number of the shore station in the first column, the ground elevation in the second column, and the elevation of the water surface in the third column. In the column headed Remarks is given all necessary information concerning the details of measurements, stage of water, etc. On the right-hand page of the notebook are given the sounding measurements. These are expressed in the form of fractions, the numerator designating the depth, in feet, and the denominator the distance from the shore station for each sounding. Thus, the fraction $\frac{6.0}{10.0}$ represents a depth of 6.0 feet at a distance of 10.0 feet from the shore station. The notes given in Form 6, when platted to scale on cross-section paper, show the cross-section of the canal for each station for which sounding notes are given.

PLATTING THE SOUNDINGS

51. General Methods.—Soundings are platted in various ways, according to the methods by which they are located. When located by ranges or courses, they are platted as follows: Each range or line on which soundings have been made is first platted to scale, in pencil, in the proper position on the map or chart. Then, the distances between the soundings on that range and the distance of each sounding from the end of the range being known, these distances are scaled on the pencil line and the position of each sounding as thus located is marked by a dot.

When the soundings are located by means of two transits on shore, as described in the third method, the base line is platted to scale in its proper position on the map and from each of its ends pencil lines are drawn making angles with the base equal to the angles measured in locating the soundings. The lines thus drawn represent the lines of

sight from the ends of the base to the positions of the soundings, and their directions are determined by the measured angles given in the notes. The intersection of corresponding lines drawn from the opposite ends of the base, representing the lines of sight of two simultaneous observations to a given sounding, will locate the sounding on the map.

In Fig. 33, *A B* represents a given base line as platted. The dotted lines *A–1*, *A–2*, *A–3*, and *B–1*, *B–2*, *B–3*, represent the directions of lines of sight to the soundings *1*, *2*, *3*. These lines are laid off at the observed angles as recorded in the notes. The intersections of the corresponding lines drawn from opposite ends of the base line give the locations of the respective soundings.

Soundings that have been located by this method can also be platted in the following manner: The distances from

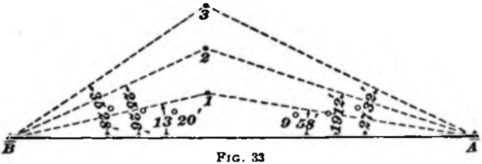


FIG. 33

each sounding to the respective extremities of the base line are calculated from the field notes. Then, the base line having been platted to scale in its proper position on the map, from its extremities as centers and with radii respectively equal to the two corresponding distances calculated for a given sounding, the arcs of two circles are drawn lightly in pencil with a pair of compasses. The intersection of the two arcs is the location of the sounding.

This method of platting is not nearly so expeditious as the method by the intersection of straight lines drawn from the instrument points, since the former method involves the calculation of two distances for each sounding, whereas the latter requires no calculation. It is sometimes valuable as a check, however, or to apply as a test in case of doubt regarding the position of a sounding.

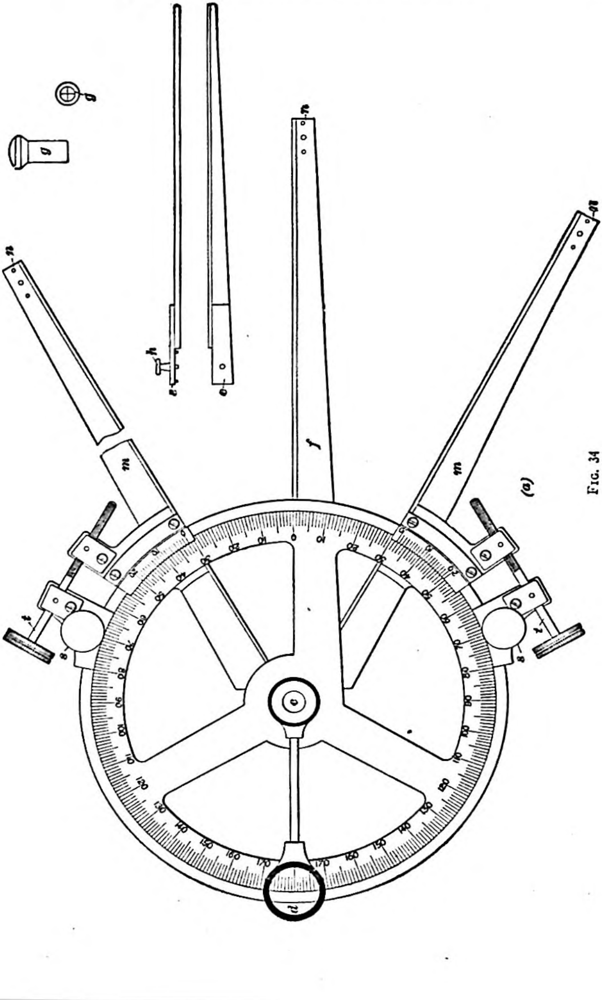


Fig. 34

52. The Three-Arm Protractor.—If the soundings have been located by sextant observations, as described in the fourth method, the most convenient way to plat them is by the use of what is called a **three-arm protractor.**

This instrument, which is sometimes called a **station pointer,** consists of a graduated metal circle, to which is attached a fixed arm *f*, Fig. 34, and two movable arms *m*, *m*. The movable arms revolve around a central point, which is the center of the graduated circle. One edge of the fixed arm and the inner edges of the movable arms extend outwards radially in line with the central point, and are beveled, as shown. The circle is divided into 360 degrees, with the zero point opposite the beveled edge of the fixed arm, which is also known as the **zero arm**, so that the prolongation of this beveled edge passes through the zero mark on the circle and also through the center *c* of the instrument. Each movable arm is provided with a vernier, as shown in the figure, and also with a clamp screw *s* and tangent screw *t*. A magnifying glass *d* is pivoted and hinged to the center of the circle and swings parallel to the graduations.

Each instrument is usually provided with three interchangeable centers, which are cylindrical in form, as shown at *g*. Each center fits snugly into a cylindrical opening *c* in the center of the instrument. One center has a glass bottom, with two etched lines intersecting at the central point; another center has a transparent horn bottom with a small hole at the central point, through which a pencil point can be inserted; and the third center is provided with a spring needle point for pricking the central point into the drawing paper.

Three-arm protractors are made of several sizes. The graduated circle is usually from 5 to $6\frac{1}{4}$ inches in diameter, and the arms are from 15 to 18 inches in length. Extensions for lengthening the protractor arms are furnished with each instrument. Each extension, as shown at *e*, *e*, Fig. 34, is provided with a splice to which are attached three studs that fit into corresponding holes at the end *n* of the protractor arm. After fitting the studs in place, the extension is secured

to the protractor arm by tightening the thumbscrew *h*. The extensions are used when soundings are to be platted that are beyond the reach of the regular protractor arms.

Before using a three-arm protractor, it is a good plan to carefully test the alinement and centering of the arms. To do this, place the protractor on the drawing board and draw lines along the straight edges of the three arms, then remove the protractor and prolong the lines inwards, noticing whether the three lines intersect in a common point. The operation should be repeated several times with the arms in different positions. If the three lines intersect in a common point for all positions of the arms, they may be considered to be truly centered.

53. The three-arm protractor is used almost exclusively for the purpose of platting soundings that have been located by sextant angles from the sounding boat. The way of using it is as follows: The movable arms of the protractor are set at the marks on the graduated circle designating the two sextant angles for any given sounding, and are firmly clamped. The instrument is then placed on the chart in such a position that the beveled edges of the three arms will pass through the platted positions of the three fixed points. This is done by placing the instrument on the paper with the beveled edge of the fixed or zero arm passing through the middle point, and sliding it around on the paper until the beveled edges of the two clamped arms also pass through the two respective outside points. The center of the instrument will then represent the position of the sounding. This point is marked by a pencil dot if a horn center is used, or pricked on the chart if a needle-point center is in the protractor at the time.

54. The Tracing-Paper Method.—When no three-arm protractor is available, soundings that have been located by sextant observations can be platted by means of a piece of tracing paper. Three lines are drawn on tracing paper in such positions as to intersect at a common point and include the two angles measured for any given sounding, the middle

line forming a side of each angle. Then, to locate the sounding, the tracing paper is placed on the map in such a position that the three lines will pass through the platted positions of the three fixed points. The intersection of the three lines will then be the position of the sounding, which is pricked through the tracing on the map or chart.

HYDROGRAPHIC MAPS AND CHARTS

55. Maps or charts of hydrographic surveys should be drawn in accordance with the principles stated in *Mapping*, Parts 1 and 2. An outline map of a river or lake survey should show the lines and angles of the outline survey, and the triangulation stations, if any. It should also show the shore line and such details of the adjacent topography as may be considered necessary.

A complete hydrographic map of a river, lake, or reservoir should show, in addition to the outline of the water surface and the adjacent topography, the form or contour of the river bed or of the submerged portion of the containing valley or basin. In order to do this effectively, lines of equal depth should be drawn; these lines show the contours of the submerged area and correspond to contour lines on a topographical map. They are located and drawn on a hydrographic map in the following manner: The soundings are platted, the position of each sounding is indicated on the map by a small dot, and the depth of each sounding is written directly over its location on the map. The lines of equal depth or the subaqueous contours are then located and drawn according to the method described in *Mapping*, Part 2, for platting contours. The contour interval will vary according to the importance of the survey, the frequency of the soundings, and the object for which the survey is made.

56. Navigation Charts.—A navigation chart of a river, lake, harbor, or other navigable body of water should show, in addition to the shore line and the adjacent

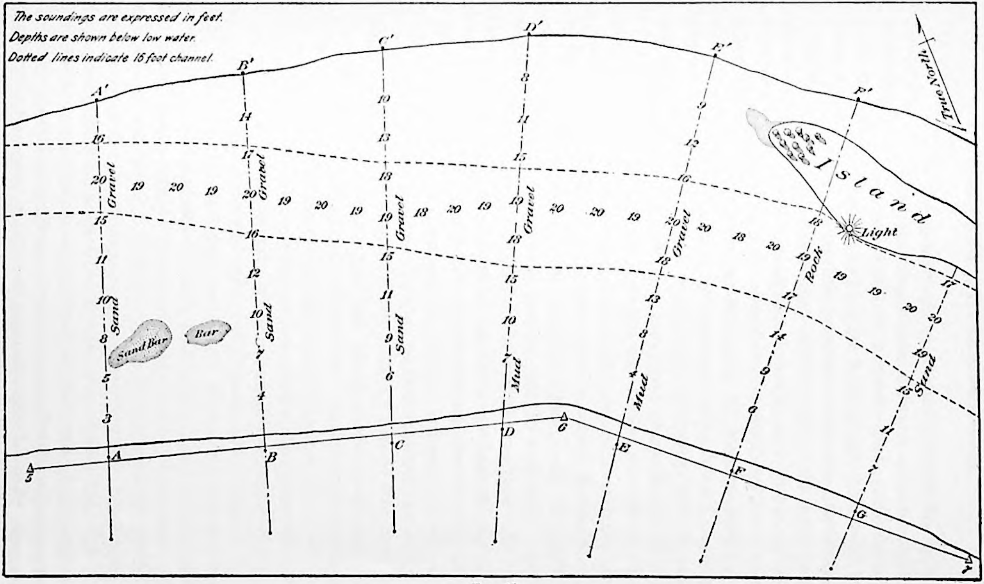

The soundings are expressed in feet.
Depths are shown below low water.
Dotted lines indicate 16 foot channel.
A'
B'
C'
D'
E'
F'
True North
Island
Light
Sand Bar
Bar
Gravel
Sand
Mud
Rock
A
B
C
D
E
F
G
5
6
7

Fig. 35

topography, the position of the navigable channel and of all rocks, sand bars, reefs, sunken wrecks, or other obstacles to navigation. In a chart of a navigable river, it is customary to show both banks and such of the adjacent topography as is desired; also the positions of islands and of such obstacles to navigation as may exist. Contour lines are drawn showing the navigable channel and the outlines of sand bars and shoals. The depths of other parts of the stream or body of water are written in the positions where the soundings are made. The depths are usually expressed in feet, and are always so expressed in shallow water. In some cases fractional half feet are used, but not smaller fractions. Soundings in the sea where the depths exceed 18 feet are usually expressed in fathoms, a fathom being equal to 6 feet, but there is no uniform practice in the use of units for depth.

Fig. 35 represents a chart of a portion of a navigable river. The line of the survey is drawn in a light full line, and the angle stations are designated by numbers. The depths of soundings, in feet, are written in figures at the places where the soundings were made, and the character of the bottom is written under the figures expressing the depths. The limits of the navigable channel, which has a minimum depth of 16 feet, are shown by the dotted lines. The ranges on which the soundings were made are shown in the figure for purposes of illustration, but this is not customary in practice. In the field work of locating the soundings, the sounding ranges were laid out across the axis of the stream and range signals were established on both banks to fix the position of each range. The soundings were located by angles measured with a transit on shore, as described in Art. 38. The boat containing the sounding party started on the south side of the river and moved along range *A* to the north bank; the soundings were made at the required intervals as the boat progressed. After traversing range *A*, the boat proceeded to the north end of range *B*, and then moved southwards along that range while soundings were taken at regular intervals, until the depth of sounding indicated that the deepest part of the channel had been reached. Then, in

order to sound the deepest part of the channel, the boat was headed in a direction approximately at right angles to the range *B*, and propelled at a uniform speed toward the range *A*, soundings being made at regular intervals of time until the boat reached that range. The time taken to traverse the distance between the two ranges was noted, as was also the number of intermediate soundings and the time interval between soundings. Then the distance between the two ranges, the time taken by the boat to traverse this distance, the number of intermediate soundings, and the time interval between successive soundings all being known, the locations of the intermediate soundings were interpolated in the manner described in Art. 36.

After the channel soundings between ranges *A* and *B* were made, the boat returned to range *B*, and sounding work on that range was resumed from the place indicated by signal from the transitman on shore. After range *B* was sounded, the boat proceeded to range *C* and moved northward along that range to the deepest part of the channel, then along the deep channel westwards to range *B*, soundings being made at regular intervals in the manner just described. The boat then returned to range *C* and proceeded northwards until the entire range had been sounded. It then proceeded to range *D* and sounded southwards along that range to the south bank, and so on back and forth across the river until all the ranges were sounded. Successive ranges were traversed in opposite directions and side trips were made for the channel soundings between each two adjacent ranges. For locating soundings made on ranges *A* and *B*, the observer was at the instrument point designated as Station 5, with the vernier of his transit at zero when the telescope was directed toward Station 6. After range *B* was sounded the transit was moved to Station 6 and set up over that station, from which soundings made on the remaining ranges were located. For locating soundings on ranges *C* and *D*, the vernier was set at zero when the telescope pointed to Station 5; and for locating soundings on ranges *E* and *F*, the vernier was set at zero when the telescope pointed to Station 7.

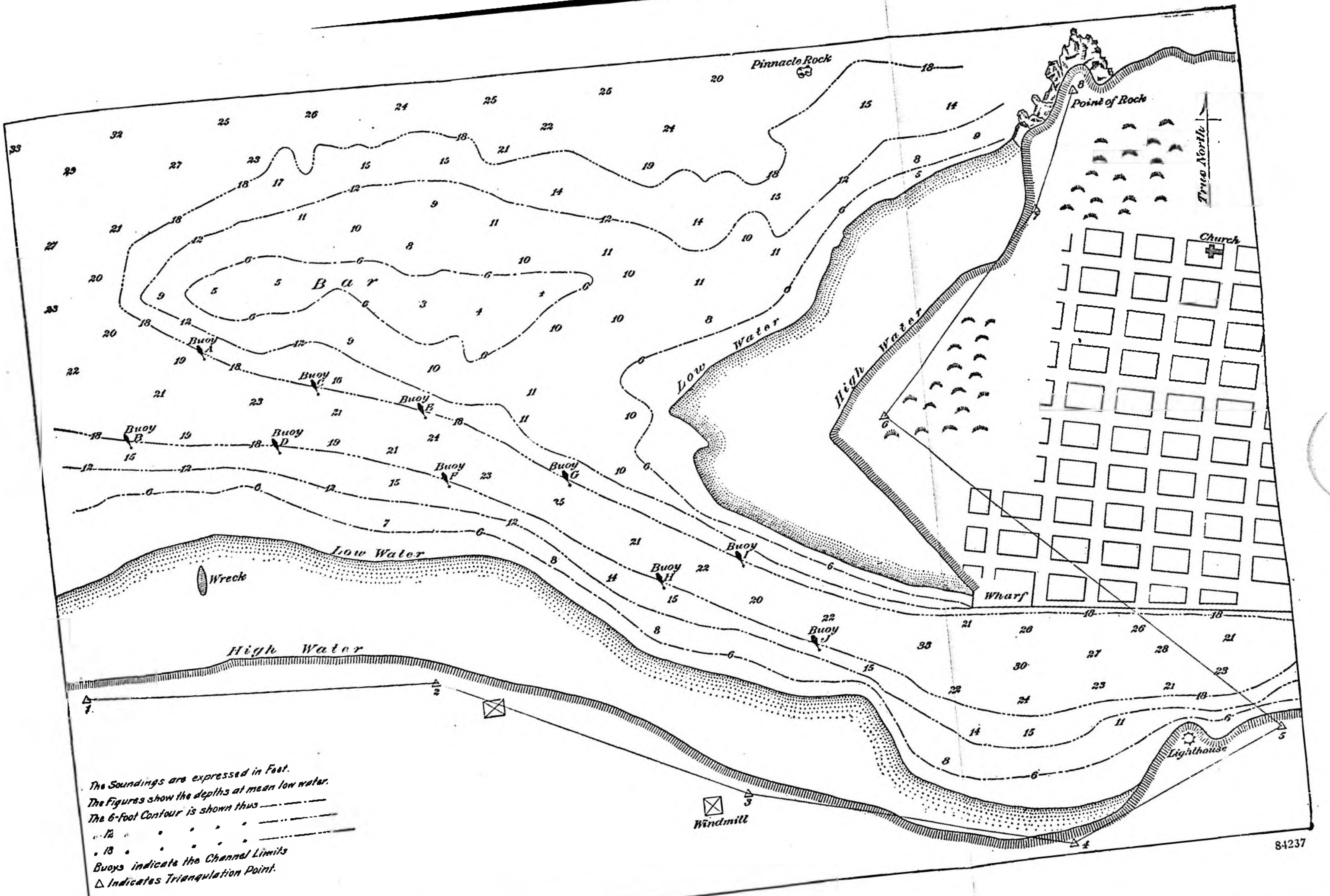
57. Chart of Harbor.—A navigation chart of the entrance to a harbor is shown in Fig. 36. The figures expressing depths, in feet, are written at the places where the soundings were made. Lines of equal depth are drawn at vertical intervals of 6 feet up to 18 feet, the depth of the navigable channel. Buoys marking the limits of the channel are shown in their proper positions along the 18-foot contour. The soundings in the southeastern part of the harbor, east of a line joining Station 3 and the buoy marked *H* were located by the intersections of transit lines observed from shore. In making the observations, the survey lines extending from Station 3 to Station 4 and from Station 4 to Station 5 were used successively for base lines. The buoys were located in the same manner, the transitmen occupying successive survey stations and using the survey lines extending between the stations as bases. The soundings farther from shore were located by sextant angles observed in the sounding boat to three fixed shore points; namely, the church, the lighthouse, and the windmill near Station 3.

MEASUREMENT OF VOLUME

CAPACITY OF A LAKE OR RESERVOIR

METHOD BY CONTOURS

58. Description of Method.—Different methods may be employed for determining the volume of water contained in a lake or reservoir, but the method by contour lines, about to be described, is probably the most accurate. An outline survey of the lake is made by traverse, stadia, or triangulation, as may be best suited to the case. The outline of the lake, as thus determined, is the surface contour. By means of soundings, the subaqueous contours of the containing valley or basin are determined at suitable intervals. The contour interval, or vertical distance between adjacent contours, is fixed according to the slopes of the valley or basin and the degree of accuracy required. The



Pinnacle Rock
Point of Rock
True North
Church
Bar
Low Water
High Water
Buoy A
Buoy B
Buoy C
Buoy D
Buoy E
Buoy F
Buoy G
Buoy H
Buoy I
Buoy J
Wharf
Wreck
Lighthouse
Windmill
The Soundings are expressed in Feet.
The Figures show the depths at mean low water.
The 6-Foot Contour is shown thus
" 12 " " " " "
" 18 " " " " "
Buoys indicate the Channel Limits
△ Indicates Triangulation Point.
84237

FIG. 36

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notes thus obtained are then platted, and a map is made showing the outline of the water surface and the several contour lines.

The solid figure included between any two adjacent contours will resemble a prismoid, whose parallel end surfaces are the surfaces enclosed by the respective contour lines, and whose perpendicular length or height is the contour interval. The area of the water surface and the area enclosed by each contour line can be determined from the plat by any of the methods for finding the areas of irregular figures described in *Trigonometry*, Part 2. When the areas enclosed by the various contours, which form the end areas of the several prismoids, are known, the volume of each prismoid can be found approximately by multiplying one-half the sum of its end areas by its height. The sum of the volumes of the several prismoids will be the volume of water in the lake. This is what is known as the **end-area method** of calculating volumes.

59. Volume by End-Area Method.—Suppose that Fig. 37 represents the plat of a lake whose capacity is

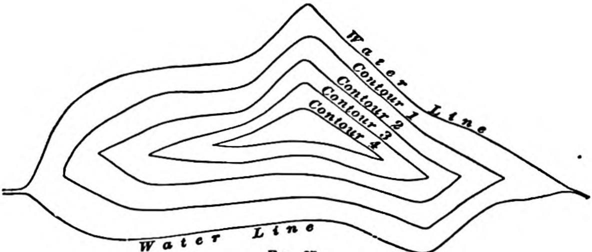

FIG. 37

required. Let A_0, A_1, A_2, A_3, and A_4 denote the areas bounded by the water-line and by the contours *1*, *2*, *3*, and *4*. respectively; let v_{0-1}, v_{1-2}, v_{2-3}, and v_{3-4} denote, respectively, the volumes of the prismoids included between the water surface and the first contour, and between the successive contours; also, let h denote the contour interval, and V the

total volume. By the method of average end areas, the approximate volumes of the several prismoids are

$$v_{0-1} = \frac{A_0 + A_1}{2} \times h$$

$$v_{1-2} = \frac{A_1 + A_2}{2} \times h$$

$$v_{2-3} = \frac{A_2 + A_3}{2} \times h$$

$$v_{3-4} = \frac{A_3 + A_4}{2} \times h$$

The total volume of the lake or reservoir is equal to the sum of the volumes of the several prismoids as expressed by the preceding equations, or

$$V = v_{0-1} + v_{1-2} + v_{2-3} + v_{3-4} = h\left(\frac{A_0}{2} + A_1 + A_2 + A_3 + \frac{A_4}{2}\right)$$

In order to express this as a general formula applicable to any number of contours, it may be written in the form

$$V = h\left(\frac{A_0}{2} + \Sigma A_m + \frac{A_n}{2}\right)$$

In this formula,

A_0 = area included by surface contour;

A_n = area included by lowest contour;

ΣA_m = sum of areas included by the intermediate contours.

EXAMPLE.—Suppose that in Fig. 37 the contour interval is 5 feet and that the areas enclosed by the several contours are as follows: A_0 = 13,350 square feet, A_1 = 8,100 square feet, A_2 = 4,280 square feet, A_3 = 1,925 square feet, and A_4 = 520 square feet; find the volume of water in the lake, in cubic feet, by the end-area method.

SOLUTION.—By substituting the given values in the formula, the volume of water is found to be

$$V = 5 \times \left(\frac{13,350}{2} + 8,100 + 4,280 + 1,925 + \frac{520}{2}\right) = 106,200 \text{ cu. ft.} \quad \text{Ans.}$$

60. Volume by Prismoidal Formula.—If the volumes of the prismoids are calculated by the prismoidal formula, two adjacent prismoids are taken as one prismoid whose height is equal to twice the contour interval. The area included by the contour that lies between the two prismoids

taken is considered the middle area of the prismoid and so used in tne formula. By thus combining the first two prismoids of Fig. 37 and applying the prismoidal formula given in *Geometry*, Part 2, the expression for their volume is

$$v_{0-1} + v_{1-2} = \frac{2h}{6}(A_0 + 4A_1 + A_2)$$

The volume of the last two prismoids is

$$v_{2-3} + v_{3-4} = \frac{2h}{6}(A_2 + 4A_3 + A_4)$$

By adding these two expressions, the total volume of the lake is found to be

$$V = v_{0-1} + v_{1-2} + v_{2-3} + v_{3-4}$$
$$= \frac{h}{3}(A_0 + 4A_1 + 2A_2 + 4A_3 + A_4)$$

In order to express this as a general formula applicable to any number of contours, it may be written in the form

$$V = \frac{h}{3}(A_0 + 4\Sigma A_1 + 2\Sigma A_2 + A_n)$$

In this formula,

A_0 = area included by surface contour;
A_n = area included by lowest contour;
ΣA_1 = sum of areas included by intermediate contours whose subscripts are odd numbers;
ΣA_2 = sum of areas included by intermediate contours whose subscripts are even numbers.

EXAMPLE.—Suppose that in Fig. 37 all values are the same as in the example solved in Art. 59; namely, h = 5 feet, A_0 = 13,350 square feet, A_1 = 8,100 square feet, A_2 = 4,280 square feet, A_3 = 1,925 square feet, and A_4 = 520 square feet; what is the volume of water in the lake, in cubic feet, as determined by the prismoidal formula?

SOLUTION.—By substituting the given values in the formula,

$$V = \frac{5}{3}(13{,}350 + 4 \times 8{,}100 + 2 \times 4{,}280 + 4 \times 1{,}925 + 520)$$
$$= 104{,}217 \text{ cu. ft.} \quad \text{Ans.}$$

61. Construction for Interpolating Contour.—It is evident that the prismoidal formula can be applied to the prismoids in pairs, as just described, only when there is an even number of prismoids. When there is an odd number

of prismoids, the last prismoid may be computed separately by the method of average end areas, or by interpolating a middle contour on the contour map, calculating the area included by it, and then applying the prismoidal formula. The middle contour can be interpolated as follows: The two end contours are platted to the same scale, preferably on cross-section paper, the smaller inside the larger, making the two figures concentric as nearly as practicable. A third contour is then drawn in such position that each point will be midway between the corresponding points of the inner and outer figures. This interpolated contour can be sketched in largely by the eye, aided to such an extent as may be desired by measurements on lines drawn radially from a point approximately in the center of the figure. The area of the surface included by this interpolated contour may be taken as the middle area of the prismoid. This area can be easily determined by means of the cross-section paper or by the planimeter.

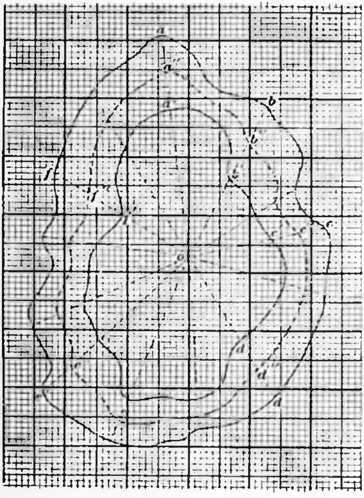

FIG. 38

Thus, in Fig. 38, $a\,b\,c\,d\,e\,f$ and $a'\,b'\,c'\,d'\,e'\,f'$ represent the contours including, respectively, the upper and the lower base of a prismoid, as platted on cross-section paper. The contour represented by the dotted line $a''\,b''\,c''\,d''\,e''\,f''$ lies midway between the boundaries of the two bases. This contour

is constructed or interpolated in the following manner: The point o is chosen as the center and the radial lines oa, ob, oc, etc. drawn to the outer contour; a', b', c', etc. are the points where these lines cross the inner contour. By measurement, the point a'' is located on the radial line oa midway between a and a'; in like manner, b'' is located midway between b and b'; c'' is located midway between c and c', etc. The contour is then sketched through the points a'', b'', c'', d'', e'', and f'', as represented by the dotted line. The area of the surface enclosed by this interpolated contour is then determined by counting the squares of the cross-section paper, and is taken as the middle area of the prismoid.

EXAMPLES FOR PRACTICE

1. Suppose that the areas bounded by the water-line of a lake and by contours 1, 2, 3, 4, and 5 are as follows: A_0 = 15,450 square feet, A_1 = 10,240 square feet, A_2 = 8,360 square feet, A_3 = 7,730 square feet, A_4 = 6,890 square feet, and A_5 = 5,240 square feet. If the contour interval is 10 feet, calculate the volume of water in the lake, in cubic feet, by the end-area method. Ans. 435,650 cu. ft.

2. Suppose that the areas bounded by the water-line of a lake and by contours 1, 2, 3, 4, 5, and 6 are as follows: A_0 = 14,320 square feet, A_1 = 10,280 square feet, A_2 = 9,360 square feet, A_3 = 7,480 square feet, A_4 = 5,780 square feet, A_5 = 4,760 square feet, and A_6 = 3,250 square feet. If the contour interval is 5 feet, calculate the volume of water in the lake by the prismoidal formula. Ans. 229,880 cu. ft.

METHOD BY PARALLEL CROSS-SECTIONS

62. Description of Method.—The following is also a good method for determining approximately the capacity of a lake or reservoir: A survey is made to determine the outline of the water surface, which is platted accurately to scale. Then, at selected points, parallel ranges are laid out across the lake, dividing its surface into trapezoids, as illustrated in Fig. 39. If the shores of the lake are irregular, the ranges are so located that straight lines connecting the points where the adjacent ranges intersect the shore line will be as much inside as outside of the water-line. By the

aid of the plat this can usually be done with a reasonable degree of accuracy. The small irregular areas included between the straight line and the water-line will then approximately balance, and it will be sufficiently accurate to consider the lake boundary as straight between adjacent ranges. The ranges having been located, soundings are made along them and the cross-section of the lake is determined on each range. The cross-sections are platted, as shown in Fig. 39, and the area of each cross-section is computed in the following manner: The

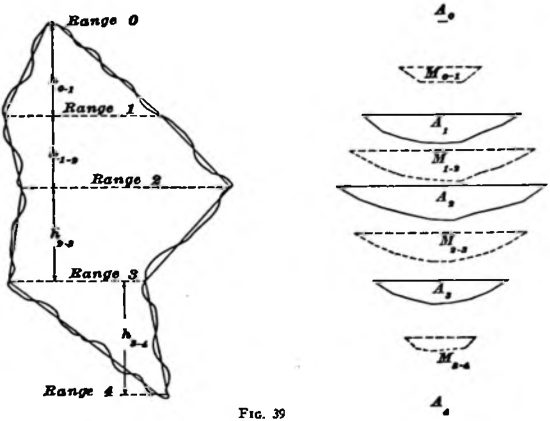

FIG. 39

section is first imagined to be divided into a series of trapezoids and triangles by vertical lines through the points at which soundings are taken. Then the area of each such trapezoid and triangle is determined, and these areas are added together to give the area of the entire section.

The lake basin is thus divided into prismoids, whose bases are the cross-sections, and whose altitudes are the perpendicular distances between adjacent ranges, and the capacity of the lake is equal to the sum of the volumes of the prismoids.

63. Volume by End-Area Method.—The approximate capacity of the lake or reservoir can be calculated by the

method of average end areas in the following manner: Let A_0, A_1, A_2, A_3, and A_4 denote, respectively, the areas of the cross-sections on the parallel ranges designated in Fig. 39 as *Range 0*, *Range 1*, *Range 2*, *Range 3*, and *Range 4*, respectively. Also, let h_{0-1}, h_{1-2}, h_{2-3}, and h_{3-4} denote, respectively, the perpendicular distances between the adjacent parallel ranges *1*, *2*, *3*, and *4*, as shown in the figure, and let v_{0-1}, v_{1-2}, v_{2-3}, and v_{3-4} denote the volumes of the corresponding prismoids. The end range *0* is merely a short straight line that represents the end of the lake and corresponds somewhat to the cutting edge of a wedge in the prismoid included between it and the cross-section on the adjacent range *1*. The same is true of the end range *4* with respect to the prismoid included between it and the cross-section on range *3*. The cross-sections on *0* and *4* thus consist of a straight line merely, and each of the areas A_0 and A_4 is zero. These areas should therefore be taken at zero in computing the volumes of the two end prismoids. By the end-area method, the expressions for the volumes of the several prismoids are: $v_{0-1} = \frac{A_0 + A_1}{2} \times h_{0-1}$; $v_{1-2} = \frac{A_1 + A_2}{2} \times h_{1-2}$; $v_{2-3} = \frac{A_2 + A_3}{2} \times h_{2-3}$; $v_{3-4} = \frac{A_3 + A_4}{2} \times h_{3-4}$.

Hence, the total volume of the lake is

$$V = v_{0-1} + v_{1-2} + v_{2-3} + v_{3-4} = \tfrac{1}{2}\left[(A_0 + A_1)h_{0-1} + (A_1 + A_2)h_{1-2} + (A_2 + A_3)h_{2-3} + (A_3 + A_4)h_{3-4}\right]$$

This formula applies to Fig. 39 or to any lake or reservoir for which the measurements are made on five parallel ranges; its application to such a case will be clearly understood. In order to make the formula applicable to measurements made on any number of ranges, it may be written in the form

$$V = \tfrac{1}{2}\left[(A_0 + A_1)h_{0-1} + (A_1 + A_2)h_{1-2} \ldots . (A_m + A_n)h_{m-n}\right]$$

In this formula, A_n denotes the area of the cross-section on the last range, and A_m that on the next to the last range.

EXAMPLE.—Suppose that the areas of the several cross-sections of the lake shown in Fig. 39, as measured along the ranges, are: $A_0 = 0$,

$A_1 = 4{,}256$ square feet, $A_2 = 6{,}322$ square feet, $A_3 = 3{,}130$ square feet, and $A_4 = 0$; also, that the perpendicular distances between ranges are: $h_{0-1} = 250$ feet, $h_{1-2} = 192$ feet, $h_{2-3} = 256$ feet, and $h_{3-4} = 310$ feet; what is the capacity of the lake, in cubic feet, as calculated by the end-area method?

SOLUTION.—By substituting the given values in the formula, the operations, in detail, are as follows:

$$
\begin{array}{lll}
(A_0 + A_1)h_{0-1} = (0 + 4{,}256) \times 250 \ . \ . = & & 1\,0\,6\,4\,0\,0\,0 \\
(A_1 + A_2)h_{1-2} = (4{,}256 + 6{,}322) \times 192 = & & 2\,0\,3\,0\,9\,7\,6 \\
(A_2 + A_3)h_{2-3} = (6{,}322 + 3{,}130) \times 256 = & & 2\,4\,1\,9\,7\,1\,2 \\
(A_3 + A_4)h_{3-4} = (3{,}130 + 0) \times 310 \ . \ . = & & \underline{\,9\,7\,0\,3\,0\,0} \\
 & 2) & 6\,4\,8\,4\,9\,8\,8 \\
 & V = & 3\,2\,4\,2\,4\,9\,4 \text{ cu. ft. Ans.}
\end{array}
$$

64. Interpolating Middle Cross-Section.—When the volume of a lake or reservoir is determined by measuring cross-sections on parallel ranges, the ranges cannot usually be located advantageously at uniform intervals, but must be located in such positions as will determine most accurately the form of the lake or reservoir. Consequently, two adjacent prismoids cannot be considered as one prismoid whose length is equal to the aggregate length of the two, and the intervening section considered as the middle section in applying the prismoidal formula, as in the preceding method. For, since the two prismoids are not of the same length, the intervening section is not the middle section. Hence, when the prismoidal formula is applied to this method, the middle area of each prismoid is determined by platting its two end cross-sections together on cross-section paper and interpolating a middle cross-section. The area of the interpolated cross-section is then determined and taken as the middle area of the prismoid. The method of interpolating the middle cross-section is similar to that for interpolating the middle contour explained in Art. 61, but is even more simple.

Let LMN and OPQ, Fig. 40, represent the bottom profiles of the measured cross-sections on two adjacent ranges. A third line RST is drawn in such position that each point is midway between corresponding points in the other two lines. In most cases, it will be sufficiently accurate to locate

points on the interpolated line midway between corresponding points that are located by soundings on the other two lines. Thus, the point S is located midway between M and P, which are points that have been located by soundings. The point R is located in the horizontal surface line midway between O and L, and the point T in the surface line midway between N and Q. The surface lines of the three cross-sections coincide between L and N. The area of the interpolated cross-section can now be determined by counting the squares of the cross-section paper, and this is taken as the middle area of the prismoid whose end areas are the areas of the cross-sections $L\ M\ N$ and $O\ P\ Q$. The middle area of the two end prismoids is determined in a similar manner. In this case the end cross-section is a straight line, and points

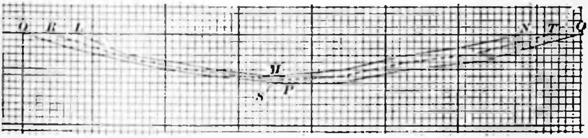

FIG. 10

on the interpolated line are located midway between the points that have been located by soundings and corresponding points on the straight line, at proportional distances from the ends of the line. When the volume of a lake or reservoir is determined by measuring cross-sections on parallel ranges and applying the prismoidal formula, the middle area of each prismoid is determined in the manner described.

65. Volume by Prismoidal Formula.—When the area of the middle cross-section has been determined, the volume of each prismoid can be determined by applying the prismoidal formula in the usual manner. The sum of the volumes of the several prismoids is the volume of water contained in the lake or reservoir.

In Fig. 39, let M_{0-1}, M_{1-2}, M_{2-3}, and M_{3-4} denote the middle areas of the prismoids whose altitudes are h_{0-1}, h_{1-2}, h_{2-3}, and h_{3-4}, respectively. Then, by applying the prismoidal

formula, the volumes of the several prismoids are found to be as follows:

$$v_{0-1} = \frac{h_{0-1}}{6}(A_0 + 4M_{0-1} + A_1)$$

$$v_{1-2} = \frac{h_{1-2}}{6}(A_1 + 4M_{1-2} + A_2)$$

$$v_{2-3} = \frac{h_{2-3}}{6}(A_2 + 4M_{2-3} + A_3)$$

$$v_{3-4} = \frac{h_{3-4}}{6}(A_3 + 4M_{3-4} + A_4)$$

Then, $V = v_{0-1} + v_{1-2} + v_{2-3} + v_{3-4}$,

or $V = \frac{1}{6}[(A_0 + 4M_{0-1} + A_1)h_{0-1} + (A_1 + 4M_{1-2} + A_2)h_{1-2} + (A_2 + 4M_{2-3} + A_3)h_{2-3} + (A_3 + 4M_{3-4} + A_4)h_{3-4}]$

In order to express this as a general formula applicable to any number of cross-sections, it may be written in the form

$$V = \frac{1}{6}[(A_0 + 4M_{0-1} + A_1)h_{0-1} + (A_1 + 4M_{1-2} + A_2)h_{1-2} + \ldots (A_m + 4M_{m-n} + A_n)h_{m-n}]$$

In this formula,

A_n = area of last section;

A_m = area of next to last section;

M_{m-n} = area of middle section;

h_{m-n} = perpendicular distance between A_m and A_n.

EXAMPLE.—Suppose that all values are the same as in the example solved in Art. 63; namely, $A_0 = 0$, $A_1 = 4{,}256$ square feet, $A_2 = 6{,}322$ square feet, $A_3 = 3{,}130$ square feet, $A_4 = 0$, $h_{0-1} = 250$ feet, $h_{1-2} = 192$ feet, $h_{2-3} = 256$ feet, and $h_{3-4} = 310$ feet; and suppose, also, that the areas of the interpolated middle sections are: $M_{0-1} = 1{,}107$ square feet, $M_{1-2} = 5{,}498$ square feet, $M_{2-3} = 4{,}536$ square feet, and $M_{3-4} = 863$ square feet; what is the capacity of the lake, in cubic feet, as calculated by the prismoidal formula?

SOLUTION.—By substituting the given values in the formula, the operations, in detail, are as follows:

$(A_0 + 4M_{0-1} + A_1)h_{0-1} = (0 + 4 \times 1{,}107 + 4{,}256) \times 250$ . . . =	2171000
$(A_1 + 4M_{1-2} + A_2)h_{1-2} = (4{,}256 + 4 \times 5{,}498 + 6{,}322) \times 192$ . . . =	6253440
$(A_2 + 4M_{2-3} + A_3)h_{2-3} = (6{,}322 + 4 \times 4{,}536 + 3{,}130) \times 256$ . . . =	7064576
$(A_3 + 4M_{3-4} + A_4)h_{3-4} = (3{,}130 + 4 \times 863 + 0) \times 310$ . . . . . . =	2040420
	6)17529436
$V =$	2921573 cu. ft. Ans.

EXAMPLES FOR PRACTICE

1. In Fig. 41, which represents a lake, BC, DE, and FG are parallel ranges on which soundings have been taken. The depths of

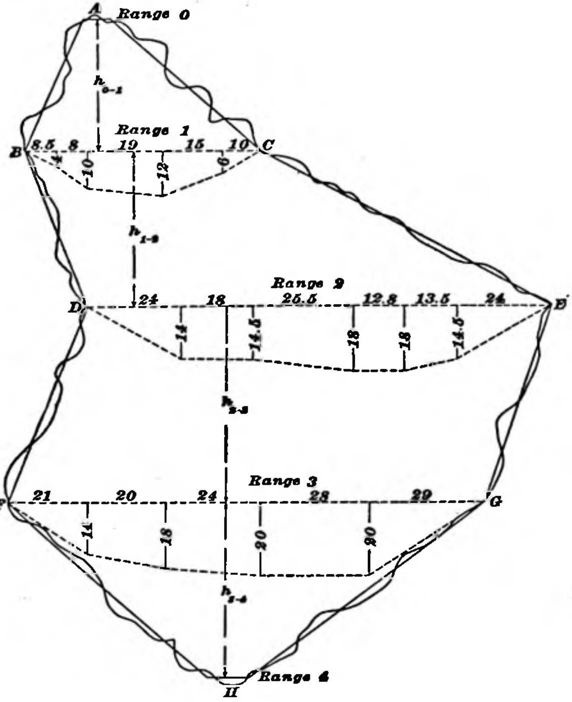

FIG. 41

the soundings and the distances between soundings are indicated in the figure. Using these values, calculate the areas A_1, A_2, and A_3 of the cross-sections on the ranges.

Ans. $\begin{cases} A_1 = 447.0 \text{ sq. ft.} \\ A_2 = 1{,}462.7 \text{ sq. ft.} \\ A_3 = 1{,}773.0 \text{ sq. ft.} \end{cases}$

2. If, in Fig. 41, the distances between adjacent ranges are $h_{0-1} = 35$ feet, $h_{1-2} = 42$ feet, $h_{2-3} = 54$ feet, and $h_{3-4} = 48$ feet, what is the capacity of the lake as determined by the method of average end areas? Ans. 177,840 cu. ft.

3. Plat the cross-sections shown in Fig. 41 to a horizontal scale of 1 inch = 20 feet and a vertical scale of 1 inch = 10 feet.

4. In Fig. 41, the areas, in square feet, of the middle sections of the various prismoids are found to have the following values: Between ranges *0* and *1*, $M_{0-1} = 131.4$; between ranges *1* and *2*, $M_{1-2} = 856.3$; between ranges *2* and *3*, $M_{2-3} = 1{,}626.7$; between ranges *3* and *4*, $M_{3-4} = 487.3$. What is the capacity of the lake, according to the prismoidal formula? Ans. 160,480 cu. ft.

CAPACITY OF A VALLEY OR BASIN FOR WATER STORAGE

66. By Contours.—If close results are desired, it is best to make a complete topographical survey of the area to be flooded and construct a contour map of the area, employing the methods described in *Topographic Surveying*. The general method is as follows: The location of the dam for impounding the water having been selected, the elevation of the spillway or overflow is decided on; this determines the height of the water in the basin. The **spillway** is that part of the dam over which the waste water is allowed to flow, and is usually somewhat lower than the crest of the dam. The impounded water will rise to a height corresponding to the elevation of the spillway and will form a pond or lake whose boundary will be a contour line extending around the border of the basin. This line, whose position thus defines the limits of the area overflowed by the water, is called the **flow line**. In Fig. 42 the flow line, which is at the elevation of the spillway, is one contour interval lower than the crest of the dam.

After the survey has been made, the flow line, the successive contours, and the outline of the projected dam are platted, as shown in Fig. 42. The planes of the contours, including that of the flow line, will intersect the face of the dam in a series of horizontal lines, as shown. A line joining the ends of these horizontal lines on the inner face of the dam, at the points where they meet the sides of the valley,

will indicate the inner outline of the base of the dam, or the inner toe of the slope, as shown in Fig. 42. A similar line will indicate the outer toe of the slope. Only the contour lines and flow lines need be considered, however, in determining the capacity of the basin. The areas enclosed by the flow line and the several contour lines are either calculated or measured with a planimeter, and the capacity of the reservoir is determined by the method of average end areas or by the prismoidal formula, as explained in preceding articles.

EXAMPLE.—Suppose that in Fig. 42 the contour interval is 5 feet and that the areas enclosed by the several contours are as follows: A_0 = 9,475 square feet, A_1 = 7,415 square feet, A_2 = 4,175 square feet, A_3 = 1,810 square feet, and A_4 = 685 square feet; what is the capacity of the reservoir, in cubic feet, as determined: (*a*) by the end-area method? (*b*) by the prismoidal formula?

SOLUTION.—(*a*) Substituting the given values in the formula in Art. 59,

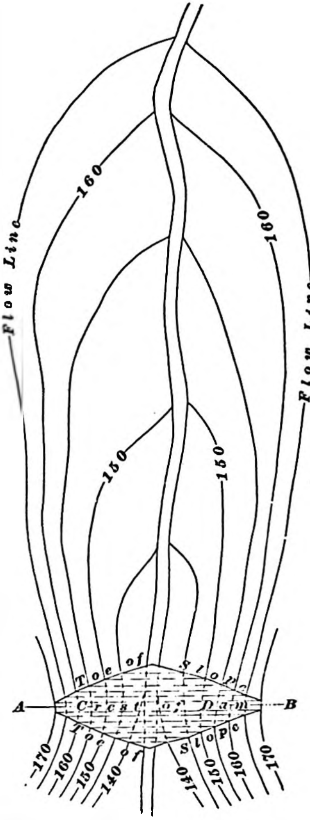

FIG. 42

$$V = 5\left(\frac{9,475}{2} + 7,415 + 4,175 + 1,810 + \frac{685}{2}\right) = 92,400 \text{ cu. ft.} \quad \text{Ans.}$$

(*b*) Substituting the given values in the formula in Art. 60,

$$V = \frac{5}{3}[9,475 + 4(7.415 + 1,810) + 2 \times 4,175 + 685] = 92,350 \text{ cu. ft.}$$

EXAMPLES FOR PRACTICE

1. From a survey made of a reservoir to determine its capacity, the areas enclosed by the flow line and the four successive contours are found to be as follows: $A_0 = 4{,}095$ square feet, $A_1 = 3{,}156$ square feet, $A_2 = 2{,}369$ square feet, $A_3 = 1{,}854$ square feet, and $A_4 = 1{,}044$ square feet; if the contour interval is 4 feet, what is the capacity of the reservoir as determined by the method of average end areas?

Ans. 39,794 cu. ft.

2. What is the capacity of the reservoir referred to in the preceding example, as determined by the prismoidal formula? Ans. 39,889 cu. ft.

---

67. By Parallel Cross-Sections.—The capacity of a valley or basin for water storage can also be determined approximately as follows: A site having been selected for a dam, the elevation of the spillway is fixed and a survey is made to determine the location of the flow line on the ground. A plat of the survey is made showing the flow line and the outline of the projected dam. Suitable locations are then selected for a series of parallel cross-lines joining points on the flow line, situated on opposite sides of the valley. These cross-lines are located in such positions as to divide the area enclosed by the flow line into trapezoids. The cross-lines are located in such positions that straight lines joining the ends of adjacent cross-lines will either coincide with the flow line or lie equally on both sides of it. This can usually be done easily by the aid of the plat even when the flow line is quite irregular.

The locations for the parallel cross-lines having been determined from the plat, the lines are located and measured on the ground, and levels are taken over them, thus determining the cross-section of the valley within the flow line on each of the parallel cross-lines. The profile of this cross-section is platted, preferably on cross-section paper, and a straight line is drawn joining the points where the profile intersects the flow line. This straight line is horizontal and corresponds to what will be the water surface when the basin or reservoir is full of water to the flow line, and the cross-section thus formed represents what will be the cross-section

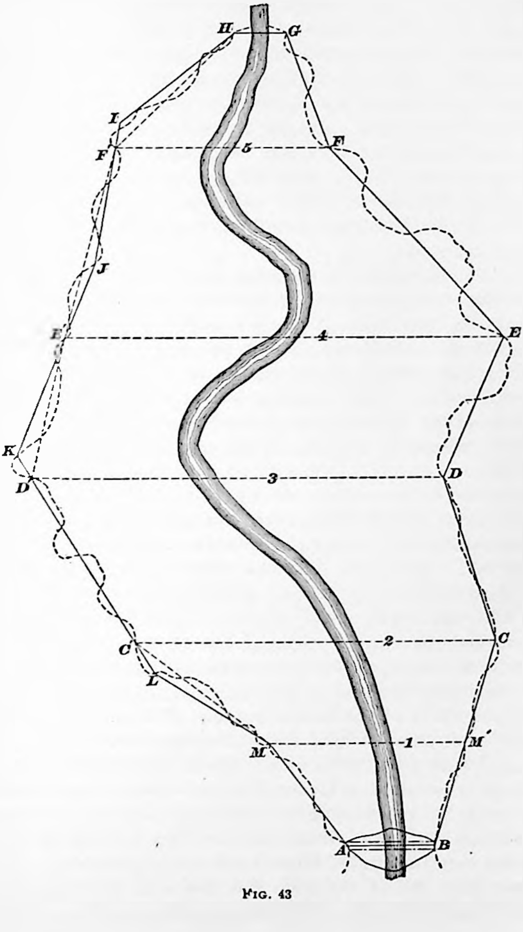

FIG. 43

of the water. The several cross-sections thus determined correspond to the cross-sections of a lake as obtained by soundings. The perpendicular distances between adjacent cross-sections are measured on the ground, calculated from the outline survey or scaled from the plat. The area of each cross-section is found, and the volume of each prismoid and total volume of the lake are determined by the end-area method as described in Art. **63**, or by the prismoidal formula, as in Art. **65**. In the latter case, the middle section may be interpolated, as described in Art. **64**, or measured on the ground.

Let Fig. 43 represent the plat of a closed survey around the limits of the reservoir, following the approximate position of the flow line. Such a position is obtained for the survey line by following along the side of the valley and locating each station of the survey at or near the elevation of the flow line. The irregular line is the flow line. $A B$ is the axis of the dam, and the dotted lines *1*, *2*, *3*, etc. are the parallel cross-lines that divide the area enclosed by the flow line into trapezoids. One end of each cross-line is located at a station of the outline survey, as at C, D, E, F, or M, but the opposite end of the line will not usually fall at a station, but at some intermediate point on the line, as at C', D', E', F', or M'. If straight lines are drawn joining such ends of the cross-lines as lie at intermediate points on the survey line with the ends of the adjacent cross-lines, the lines so drawn and the corresponding parts of the survey line will form small triangles, some of which will lie inside, and some outside, of the original outline survey. Thus, the line $D' E'$ forms one side of the small triangle $D' E' K$; the line $E' F'$ forms one side of the small triangle $E' J F'$, etc. The effect of such triangles is usually small, however, and in most cases it is possible to locate the cross-lines in such positions that straight lines joining the corresponding ends of adjacent cross-lines will approximate the flow line sufficiently closely, and the small triangles formed may be neglected.

The lines $B C$, $C D$, $D E$, $E F$, and $F G$ are sides of the survey and it is seen from the plat that they cut off small

irregular areas that lie between the survey line and the flow line on both sides of the latter, and that these areas will approximately balance; that is, the areas lying on the outside of the survey line will be approximately equal to those lying inside of it. Similarly, if the points H and F', F' and E', E' and D', etc. are joined by straight lines, these lines will cut off approximately equal areas on both sides of the flow line. The trapezoid $F' H G F$ will then contain approximately the same area as the irregular figure $F' I H G F$ bounded by the flow line; and similarly, each trapezoid included between any two adjacent parallel cross-lines will be approximately equal to the figure included between the same two cross-lines and limited by the flow line. The valley or basin is thus divided into prismoids whose bases are the cross-sections measured on the parallel cross-lines, and whose altitudes are the perpendicular distances between adjacent cross-lines. From these the volume of each prismoid can be calculated as explained in Art. **65**. The capacity of the valley or basin is the sum of the volumes of the several prismoids.

EXAMPLES FOR PRACTICE

1. The areas of the several cross-sections of a valley intended for water storage are found to be: $A_0 = 0$, $A_1 = 396$ square feet, $A_2 = 678$ square feet, $A_3 = 910$ square feet, $A_4 = 720$ square feet, and $A_5 = 586$ square feet. The perpendicular distances between the cross-sections are $h_{0-1} = 40$ feet, $h_{1-2} = 45$ feet, $h_{2-3} = 50$ feet, $h_{3-4} = 32$ feet, and $h_{4-5} = 36$ feet. What will be the capacity of the reservoir, in cubic feet, as determined by the end-area method? Ans. 121,373 cu. ft.

2. Assuming the middle areas to be: $M_{0-1} = 280$ square feet, $M_{1-2} = 410$ square feet, $M_{2-3} = 802$ square feet, $M_{3-4} = 830$ square feet, and $M_{4-5} = 670$ square feet, calculate, by the prismoidal formula, the capacity of the reservoir referred to in the preceding example.
Ans. 120,744 cu. ft

METHODS FOR HYDROGRAPHIC SURVEYING ALONG COAST

METHODS FOR SOUNDING

68. Reasons for Special Methods for Hydrographic Surveying.—In many localities along the two coasts of the United States, the U. S. Coast and Geodetic Survey extends hydrographic surveys out into the ocean to a depth of 6,000 feet, or 1,000 fathoms. The fathom is the more common unit for measuring soundings made on the ocean bottom. The method of obtaining soundings by means of the hand lead line is applicable to a depth of only about 20 fathoms. For greater depths, lead-line soundings may be made by means of mechanically operated sheaves, known as sounding machines. In either case, it is necessary for the survey boat to proceed at a slow rate, and in many cases to stop altogether, during the actual making of the soundings. This requirement renders the method of obtaining deep soundings by lead line rather slow and impracticable. Also, the distance that a coastal survey extends from the shore may be so great that the shore signals or the floating signals are no longer satisfactory for complete control of the positions of the soundings.

In order to facilitate the making of coastal hydrographic surveys in deep waters and at considerable distances from the shore, the U. S. Coast and Geodetic Survey has developed special methods for obtaining soundings while the survey boat is traveling at full speed and also for locating positions when signals are not visible from the survey boat. The two methods that have been widely used for obtaining soundings are (1) the *pressure-tube method*, and (2) the *echo-sounding method*. The positions of soundings made by either of these methods may be located by one of the two following methods: (1) *precise dead reckoning* and (2) *radio-acoustic sound ranging*. Where

echo sounding is used, the positions may also be determined by observations on stars; the entire procedure is usually called *star-control echo sounding.*

69. Pressure Tube.—The pressure-tube method of measuring the depth of water consists in submerging a hollow tube that is closed at the bottom end and is provided at the upper end with a special cap through which the water can enter but the air cannot escape. The amount of water that is forced into such a tube depends on the pressure of the water, and this pressure in turn depends on the depth to which the tube is lowered. Therefore, by measuring the amount of water in the tube, the depth to which the tube was lowered can be determined. Usually, two tubes are used so that one may be submerged while the amount of water in the other is being determined.

The pressure tube of the U. S. Coast and Geodetic Survey consists of a two-foot length of brass tubing, the inside diameter of which is $\frac{1}{2}$ inch. One end of the tube is closed and the other is fitted with a special brass cap in which there is a small spiral-shaped capillary tube about 3 inches long. The sealed end of a pressure tube is weighted so that the tube will sink in a vertical position with the capped end uppermost. As the pressure tube is lowered, water is forced into it through the capillary opening, but no air can escape. The amount of water that is forced into the pressure tube depends on the pressure due to the depth of the water in which the tube is submerged. When the tube is raised out of the water, the air escapes and the water sinks to the bottom of the tube. After the tube has been brought on board the survey boat, the cap is removed and a special brass rod is inserted into the tube until the level of the contained water is forced up to the top of the tube. By means of a sliding marker on the brass rod and a specially-graduated scale that can be held against the rod, it is possible to read the depth, in fathoms, to which the pressure tube was lowered.

It is rather difficult to insert the brass rod just the right amount without spilling any of the water; and, in order to

avoid this difficulty, an electrically controlled indicator has been devised. This indicator is actuated by the brass rod that is inserted into the pressure tube. When the point of the rod strikes the water, a click is transmitted to a set of earphones in the electric circuit, and the reading of the indicator at that instant shows the depth, in fathoms, to which the pressure tube was lowered.

70. Echo Sounding.—The echo-sounding machine used by the U. S. Coast and Geodetic Survey is an electrically operated apparatus consisting of the following essential parts: An *oscillator*, which produces a sound under water; a *hydrophone*, or a device for detecting the echo of the sound as it is reflected from the bottom of the ocean below the point at which the sound was made; a *fathometer*, which is a device for measuring the interval of time between the production of the sound and the detection of its echo; a *filter*, or a device for amplifying the intensity of the echo and reducing the intensity of other under-water noises; a *motor generator*, which transforms the ship's electrical power to the proper voltage and the correct number of cycles needed for the oscillator; and the necessary wires and switches for connecting and operating the various units.

The method of echo sounding consists in producing a sound by means of an oscillator attached to the bottom of the survey boat, and obtaining an echo of the sound in a hydrophone which is also attached to the bottom of the boat. The time interval is recorded by a fathometer. However, the speed of sound in water varies between 4,740 feet and 5,220 feet per second, the exact speed depending on the temperature of the water, the pressure to which the water is subjected, and the salinity, or salt content, of the water. Usually, the depth is computed on the basis of a velocity of 4,800 feet per second, and this computed depth is multiplied by a correction factor in order to obtain the more correct depth. Correction factors for various temperatures, pressures, and salinities may be obtained from special tables that are published by the U. S. Coast and Geodetic Survey.

METHODS FOR LOCATING POSITIONS OF SOUNDINGS

71. Precise Dead Reckoning.—When the positions of soundings are to be determined by precise dead reckoning, the ship starts from a known point and runs along a course with a definite bearing for a certain distance to the point at which the first sounding is to be taken. The starting point may be a floating signal or a point located by measuring sextant angles to three floating signals. The speed of the ship is maintained as nearly constant as is possible so that the distance the ship travels can be estimated from the elapsed time; also, the course is set so as to allow for the effect of wind and current. From the first sounding, the ship is run along the proper course and for the required distance to the second sounding; and each successive sounding is located similarly from the preceding sounding. When the limiting distance from shore has been reached, the ship runs parallel to the shore for a definite distance and proceeds back toward shore on a calculated course which is parallel to the outgoing course. Finally, the position of the ship at the shore end of the trip is checked by either finishing at a floating signal or sighting on floating signals. In order to make allowance for the wind and the current, it is customary to measure the wind velocity and the set and drift of the current at the start and finish of the trip and at intervals of 2 hours during the trip.

The use of this method is confined largely to localities where the ocean bottom is comparatively level and the soundings are required only at points that are a considerable distance apart. Usually, for depths up to 15 fathoms the soundings are made about 1 to 2 miles apart; and for depths from 15 to 100 fathoms the soundings are made about 2 to 4 miles apart. Although dead reckoning is often used for locating soundings where floating signals cannot be placed economically for complete control, the use of this method is limited by the following three factors: (1) The necessity for obtaining the closing error of the courses followed by the survey boat, before the probable position of the soundings can be definitely determined; (2) the difficulty encountered in covering a definite distance at a pre-

determined speed; and (3) the probable inaccuracies in the calculated positions that may be caused by variations in the speed of the boat.

72. Radio-Acoustic Sound Ranging.—In radio-acoustic sound ranging, the soundings are made along ranges whose control points are located as follows: A bomb is exploded in the water at each control point, the exact time of the explosion is determined by observations made on the ship, and the exact

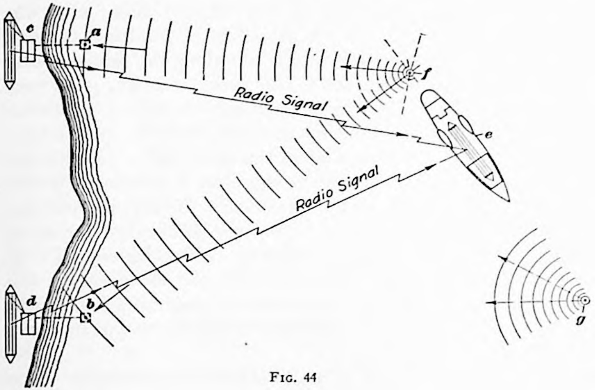

FIG. 44

time at which the sound of the explosion reaches each of two established hydrophone stations is recorded at the ship by means of a radio signal. The distance between the two hydrophone stations is known, and the distance from the control point to each of the two stations can be computed by multiplying the velocity of sound in water by the time it took for the sound to travel from the point of explosion to the respective station.

In Fig. 44 is shown diagrammatically the procedure for locating by radio-acoustic sound ranging the position of a ship that is making off-shore soundings. Two hydrophone stations

a and *b* are placed about 4 or 5 feet from the ocean bottom in 7 to 10 fathoms of water. The positions of these hydrophone stations are accurately located by sextant angles to known stations on shore. Also, each hydrophone station is connected by a cable to the transmitter of a temporary radio station, as *a* to *c* and *b* to *d*. In the bottom of the ship *e* is a hydrophone that is connected to an electrically operated recording tape, or *chronograph*. The ship is also equipped with a radio receiving set that is connected to the chronograph.

The position of the ship is determined as follows: A small bomb, which is equipped with a fuse that will cause it to explode 20 to 30 seconds after it strikes the water, is dropped overboard while the ship is traveling at a predetermined speed. The bomb will normally sink at the rate of about a fathom per second. In shallow waters, where the bomb would reach the bottom before it explodes, the bomb may be held at a certain depth by attaching it by means of a cord to a temporary buoy consisting of a paper bag filled with air. At the instant the bomb is dropped, an electrically controlled relay marks the tape on the chronograph. Also, when the bomb explodes, a indicated at *f*, the sound of the explosion is received by th hydrophone on the ship and is relayed to the chronograph. From the speed of the ship, the speed of sound in water, and the total elapsed time between the dropping of the bomb and the receipt of the explosion, the exact time of the explosion may be computed.

The sound of the explosion of the bomb at *f* also travels under water to the hydrophone stations *a* and *b*. At the instant the sound impulse is received at *a*, a signal is sent by cable to the radio station at *c*, from which it is transmitted to the ship. Likewise, at the instant the sound impulse is received at *b*, a signal is transmitted to the radio station at *d* and to the ship. As each radio signal is received by the ship's set, the chronograph records the exact time of its receipt. From these times, the calculated exact time of the explosion, and the velocity of sound in water, it is possible to compute the distances *af* and *bf*, and thus to locate point *f* accurately. If another bomb is dropped when the ship reaches point *g*, the

distances *ag* and *bg* can also be determined in the manner explained for *af* and *bf*. From the known positions of *f* and *g* and the known speed of the ship, it is possible to locate any number of soundings that may be made between points *f* and *g*. Usually, the velocity of sound in the water in the vicinity of the work is determined by tests made while the ship is near the shore, and the necessary angles to the signals can be measured with a sextant.

EXAMPLE.—Determine the distances *af* and *bf* in Fig. 44 under the following conditions: The elapsed times between the explosion of the bomb at *f* and the receipt of the signals from the radio stations at *c* and *d* are 97.84 seconds and 88.60 seconds, respectively; and the average velocity of sound in the water in the vicinity of the work is found from tests to be 4,859 feet per second.

SOLUTION.—Each of the required distances is found by multiplying the velocity of sound by the time interval between the explosion of the bomb and the receipt of the radio signal at the ship. Thus,

$$af = 97.84 \times 4{,}859 = 475{,}405 \text{ ft. Ans.}$$

and

$$bf = 88.60 \times 4{,}859 = 430{,}507 \text{ ft. Ans.}$$

73. Star-Control Echo Sounding.—The method of star control for determining the positions of soundings is particularly adaptable to soundings made by means of echo-sounding machines on ranges that extend a considerable distance from the shore. The ship is started in a calculated direction, as obtained by precise dead reckoning, from a known signal on or near the shore. When the ship reaches the end of the run, its position is determined by observations on several stars with a sextant. The observations should preferably be made on four stars that are about equally spaced around the horizon. In order to make satisfactory observations, the horizon and the stars should both be clearly visible. These conditions require an exceptionally clear sky and limit the time for making the observations to either dawn or dusk. After the star observations have been made, the ship is run back toward shore on a different course from the one for the outgoing trip and the final position of the ship is checked by observations on known stations on or near the shore.

During both the outgoing and ingoing runs, the speed of the ship should be kept as nearly constant as possible so that the distances between soundings may be calculated accurately from the time intervals between soundings. Occasionally, during a run, observations may be taken on the sun or the moon for the purpose of checking the position of the ship.

The difficulty encountered in this method is chiefly that of keeping the ship on its course and maintaining a constant speed. Also, conditions for making star observations at the end of an outgoing run are not always satisfactory, as the sky may become cloudy between the starting time and the time of completion of the run. Then the entire work must be discarded, and the run must be started again.

HYDROGRAPHIC SURVEYING

Serial 787 Edition 2

EXAMINATION QUESTIONS

Notice to Students.—*Study the Instruction Paper thoroughly before you attempt to answer these questions.* Read each question carefully and be sure you understand it; *then write the best answer you can. When your answers are completed, examine them closely, correct all the errors you can find, and* see that every question is answered; *then mail your work to us.*

(1) In order to make a hydrographic survey of a river, a base line *A B*, Fig. I, was measured, stations *C*, *D*, *E*, etc. were selected on the two sides, and all the angles in the triangles *1*, *2*, *3*, *4*, *5* carefully measured. The values of the

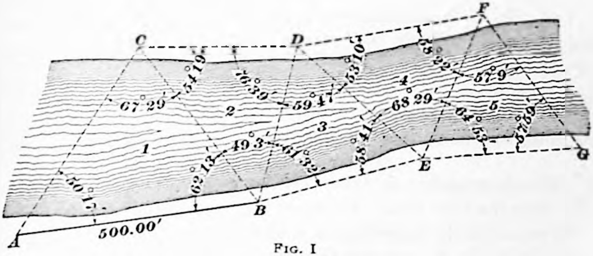

FIG. I

angles shown in the figure are those that were found by actual measurements: (*a*) Correct the angles (see Art. 6). (*b*) Having corrected the angles, compute the distances *A C*, *C B*, *C D*, *D B*, *B E*, *D E*, *D F*, *F E*, *E G*, *F G*.

Ans.

Corrected Angles			Lengths of Lines
Triangle 1	*Triangle 2*	*Triangle 3*	*A C* = 478.87 ft.
67° 29′ 20″	54° 18′ 40″	59° 47′	*C B* = 416.36 ft.
62° 13′ 20″	76° 38′ 40″	58° 41′	*C D* = 323.18 ft.
50° 17′ 20″	49° 2′ 40″	61° 32′	*D B* = 347.57 ft.
			B E = 351.57 ft.
Triangle 4	*Triangle 5*		*D E* = 357.66 ft.
			D F = 390.81 ft.
53° 9′ 40″	57° 8′ 40″		*F E* = 336.22 ft.
58° 21′ 40″	57° 58′ 40″		*E G* = 333.12 ft.
68° 28′ 40″	64° 52′ 40″		*F G* = 359.04 ft.

(2) A base line having been measured along the bank of a river, and a buoy having been placed near the middle of the river on a range at right angles to the base line, it is required to determine the distance from the base line to the buoy. Describe the necessary operations, assume the measurements, and work out the result.

(3) Explain how a sounding may be located by two angles measured simultaneously from the ends of a base line on shore. Assume the necessary measurements, make the calculations required, and describe the method of plotting the sounding on a map.

(4) What is the most accurate method of locating soundings: (*a*) in a large body of water? (*b*) in a narrow channel or creek?

(5) In very accurate work, would you use the method of locating soundings by time intervals? If not, why?

(6) A sounding is taken on a range making an angle of 60° with the base line. To locate the sounding, a transit is set at a point on the base line at a distance of 275 feet from the range, measured along the base line. If the angle between the base line and the line of sight to the sounding is 49° 12′, what is the distance along the range from the base line to the sounding?

Ans. 220.4 ft.

(7) At the moment of making a sounding, two angles were measured with the sextant, directing the line of sight from the boat to three points, *A*, *B*, and *C*, on shore. The angle between the lines *A B* and *B C* was 159° 30′, and the lengths of *AB* and *BC* were, respectively, 500 and 300 feet. The lines of sight from the boat to *A* and *B* made an angle of 23° 8′, and those to *B* and *C*, an angle of 39° 13′. Make a sketch and determine the distances of the sounding from *A*, *B*, and *C*, respectively.

Ans. $\begin{cases} 853.8 \text{ ft.} \\ 414.4 \text{ ft.} \\ 174.9 \text{ ft.} \end{cases}$

(8) Fig. II represents a contour map of a reservoir; the contour interval is 5 feet, as shown, the water-line being taken as zero depth. The areas included by the five contours are, respectively, $A_0 = 11{,}500$ square feet, $A_1 = 8{,}740$ square feet,

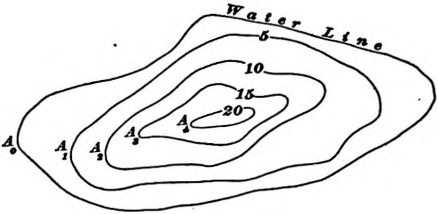

Fig. II

$A_2 = 5{,}170$ square feet, $A_3 = 2{,}650$ square feet, and $A_4 = 615$ square feet; find the volume of the reservoir, in cubic feet, by the end-area method. Ans. 113,090 cu. ft.

(9) Compute the capacity of the reservoir in the preceding question by using the prismoidal formula.

Ans. 113,360 cu. ft.

(10) In Fig. III is shown the plane of a pond. Soundings were taken along the parallel ranges $A_1 A_1$, $A_2 A_2$, etc.,

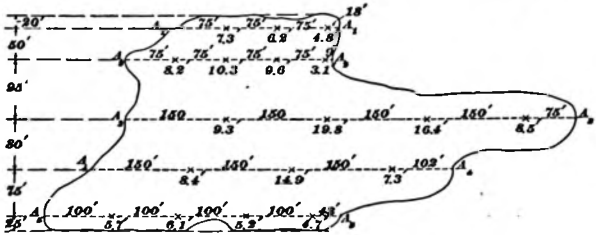

Fig. III

the latter being spaced as shown. The number under each cross-mark indicates the depth at that point; and that on the horizontal line between two cross-marks indicates the

horizontal distance between the corresponding points. Compute the areas of the cross-sections A_1A_1, A_2A_2, etc.

$$\text{Ans.}\begin{cases} A_1A_1 = 1{,}235.7 \text{ sq. ft.} \\ A_2A_2 = 2{,}237.7 \text{ sq. ft.} \\ A_3A_3 = 7{,}781.3 \text{ sq. ft.} \\ A_4A_4 = 4{,}414.8 \text{ sq. ft.} \\ A_5A_5 = 2{,}036.1 \text{ sq. ft.} \end{cases}$$

(11) From the data of the preceding example, compute the capacity of the pond, in cubic yards, using the method of end areas. Ans. 49,270 cu. yd.

(12) Still referring to Fig. III, make careful sketches showing the cross-sections A_3A_3 and A_5A_5 to a horizontal scale of 1 inch = 100 feet and a vertical scale of 1 inch = 6 feet.

Mail your work on this lesson as soon as you have finished it and looked it over carefully. DO NOT HOLD IT until another lesson is ready.

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